Estimates of a Consumer Demand System: Implications for the Incidence of Environmental Taxes

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I. Introduction

Distributional effects represent an important concern in designing and evaluating environmental policy. Most studies suggest that environmental taxes tend to be at least mildly regressive, making such taxes less attractive options for policy. This study calculates the distributional effects of a gasoline tax. Unlike most prior distributional studies, this work does not assume inelastic demand. Instead, it estimates a full matrix of demand elasticities, including cross-price elasticities, and uses these estimates to calculate the equivalent variation resulting from the tax.[1]

This paper's results should be of interest for two reasons. The first contribution is the distributional estimates themselves. Increases in the gas tax are often discussed, and distributional concerns play an important role in those discussions. While many prior studies have considered the distributional effects of the gas tax, to our knowledge, none have considered the effects of different uses for the revenue from the increased tax.

The second contribution is methodological. This study examines the importance of considering behavioral effects in calculating the incidence of environmental taxes. Ignoring demand responses significantly simplifies tax incidence analysis, and, as long as the behavioral changes are small, it will introduce little error. However, it is not clear that this will be the case for environmental taxes; proposed carbon taxes would lead to double-digit (or larger) percentage increases in fossil fuel prices, while a gasoline tax equal to marginal damage would more than double the price of gasoline. With tax changes of this magnitude, even if demand is relatively

[1] For examples of recent distributional studies, see Metcalf (1999) or CBO (2000). West (2001) allows for behavioral responses when calculating distributional effects, but does not include cross-price effects. We have found no studies that estimate the cross-price elasticity between gasoline and leisure. 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.

inelastic, the behavioral changes–and thus the error that would result from ignoring such changes in calculating incidence–may be important. In addition, these behavioral changes may differ across income groups. Our study provides incidence estimates that assume no behavioral changes as well as estimates allowing for such changes. The differences between the two sets of estimates illustrates the importance of including behavioral changes in distributional estimates.

The study also tests the importance of considering cross-price elasticities in calculating incidence. To do this, it will calculate two sets of incidence estimates that incorporate behavioral changes: one based on partial-equilibrium consumer surplus, and one based on the equivalent variation, which incorporates cross-price effects. While a small number of studies have looked at the effects of incorporating behavioral responses in calculating the incidence of environmental taxes, only one prior study, Brannlünd and Nordström (2001), incorporates cross-price elasticities, and it does not discuss the importance of such cross-price effects, nor does it provide a second set of estimates that exclude cross-price effects.[2]

Predicting the effects of incorporating cross-price elasticities is difficult; most of the intuition for distributional analysis comes from partial-equilibrium models, in which all cross-price elasticities are assumed to be zero. However, given the importance of cross-price elasticities in other contexts (the efficiency of taxation, for example), it is quite possible that such elasticities may be important here as well. In particular, the cross-price elasticity between gasoline and leisure is likely to be important when the gasoline tax revenue is used to cut the labor tax; responses to the changing labor tax rate may affect the burden of the gas tax, and vice-versa.

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[2] For example, Pearson and Smith (1991) showed that a carbon tax in the EU would be less regressive than other studies had indicated.

We use the 1996 through 1998 Consumer Expenditure Surveys, which provide detailed data on household expenditures including gasoline expenditures, on vehicle holdings, 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. 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 estimate our demand system by quintile separately for one-earner households and for two-earner households with one female earner and one male earner, and for different income quintiles within each group.

We find that increasing the gas tax is generally regressive, though this can be offset if the revenue is used to provide a lump-sum transfer to households. Incorporating demand responses in measuring incidence reduces the measured welfare cost significantly, but this effect is generally similar across income groups, so it has little effect on the measured regressivity of the tax increase. Finally, while cross-price elasticities play an important role in determining the change in the labor tax or lump-sum transfer made possible by the additional revenue from the higher tax–essentially an efficiency effect–they have little direct effect on the distribution of the burden of the tax.

Section II describes the structure assumed for the demand system, the data, and the estimation approach. Section III discusses the approach used to calculate incidence and the results of those calculations, and Section IV concludes.

II. Demand System Estimates

This study uses the demand system developed in West and Williams (2002), which is defined over three goods: leisure, gasoline, and all other goods. However, that paper estimated the demand system only for a single representative agent, whereas the present paper estimates the system separately for each income quintile. The remainder of this section describes the structure assumed for the demand system, the estimation approach, and the data used.

A. Specification of the Demand System

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 does not assume that the utility function is separable or homothetic.

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

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

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

(2) $$\log a(\mathbf{p}, w) = \alpha_0 + \sum_{k}^{n,l} \alpha_k \log p_k + \frac{1}{2} \sum_{k}^{n,l} \sum_{j}^{n,l} \gamma_{kj} \log p_k \log p_j$$

(3) $$\log b(\mathbf{p}, w) = \log a(\mathbf{p}, w) + \beta_0 \prod_{k}^{n,l} p_k^{\beta_k}$$

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

(4a) $$s_i = \alpha_i + \sum_{j}^{n,l} \gamma_{ij} \log p_j + \beta_i \log(\frac{y}{P})$$ (*i = gasoline, other goods)*

(4b) $$s_l = \alpha_l + \sum_{j}^{n,l} \gamma_{ij} \log p_j + \beta_l \log(\frac{y}{P})$$

where y is total expenditure and P is the price index defined by:

(5) $$\log P \equiv \sum_{k}^{n,l} s_k \log p_k$$

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

(6) $$\sum_{i=1}^{n,l} \alpha_i = 1$$

(7) $$\sum_{i=1}^{n,l} \gamma_{ij} = 0$$

(8) $$\sum_{i=1}^{n,l} \beta_i = 0$$

(9) $$\gamma_{ij} = \gamma_{ji}$$

Two-earner households have one leisure share equation (4b) for the household's male earner and another for the household's female earner.

Provided that these restrictions hold, (4) 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 (6) through (9) and drop the equation for other goods.

B. Data and Variable Derivation

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.

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.

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 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.

C. Summary Statistics

We estimate two demand systems: one for one-adult households and the other for two-adult households composed of one male and one female. We do not include households with adults over the age of 65. The twelve quarters in the 1996 through 1998 Consumer Expenditure Surveys have 5046 such one-adult households and 9619 two-adult households with complete records of the variables needed here. We use the full samples to correct for selection bias in the wage, and households in which all adults work the system estimation. Tables 1 and 2 list summary statistics for the one-earner and two-earner samples of workers.

Households spend about 2 percent of their income on gasoline, a bit more than 50 percent on leisure, and the remainder on other goods. The average selectivity-corrected wage in the one-earner sample is $9.73 per hour. Males in the two-earner sample make $10.11 per hour, while women make $6.53 per hour. The overall wage distribution in our sample closely follows the wage distribution in the 1997 CPS.

D. 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.[3]

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.[4]

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.[5]

Before we divide households into quintiles, we use an equivalence scale to adjust total expenditures for different family sizes. Our equivalence scale weights adults and children equally, but allows for economies of scale in consumption. In specific, we divide total expenditures by $(adults + children)^{.5}$. We pool both one-adult and two-adult households, rank them together by equivalence-scale adjusted total expenditures, and divide them into quintiles.[6]

We estimate the demand system separately for one-adult and two-adult systems, by quintile. For example, the number of observations in system estimation for quintile 1 one-adult households and the number observations of quintile 1 two-adult households (estimated separately) equals 20% of the total sample of households. We impose the restrictions in (6) through (9), drop the equation for other goods, and estimate the demand systems using three-

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3 Regressions without instruments for the wage generate results that are very similar to those presented here. We also experiment with regressions that use state gas tax rates as instruments for gas prices. Results from those regressions are also very similar to those presented here.

4 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.

5 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).

6 This equivalence scale is suggested by Williams *et al* (1998), which also considers several alternatives and finds that the choice of equivalence scale has little effect on distributional estimates. We find a similar result: changing the relative weight given to adults and children in the equivalence scale has little effect on the ranking of households.

stage least squares. We include in each system member characteristics that may affect gasoline or leisure shares: the members' age, age squared, race, sex (in the case of one-earner households only), 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. Appendix 1 contains the full results for system estimation by quintile.

Table 3 presents the compensated and uncompensated demand elasticities by quintile that are implied by the regression coefficients. These elasticity estimates aggregate together male and female leisure for two-earner households, and then aggregate together the one-earner and two-earner households in each quintile.

Compensated own-price elasticities are negative for all but the first quintile, where the own-price elasticities for leisure and for other goods are insignificantly positive. Compensated and uncompensated gasoline own-price elasticities range from about -.5 (two-earner households) to -.7, except for the top quintile, and fall in the span of estimates reported in gas demand survey articles (see Dahl and Sterner (1991) or Espey (1996)). The top quintile is substantially less responsive to increases in the price of gasoline, with own-price gas demand elasticities of roughly -.3.

III. Incidence Estimates

This section considers the incidence of a substantial increase in the gasoline tax, under a range of different assumptions about how the gas tax revenue is used and about how consumer demands react to the policy changes.

A. Modeling Incidence

We consider the effect of increasing the gasoline tax to 95 cents per gallon, which equals the marginal external damage per gallon of gasoline found in a survey by Parry and Small (2001). For simplicity, we assume that the tax is changed only for gasoline used directly by households–there is no change in the tax on gasoline used as an intermediate input–and that supply in all industries is perfectly elastic. Together, these assumptions imply that, for all goods, the change in price for a particular good will be equal to the change in the tax on that good. We also assume that labor is perfectly substitutable across different skill and ability levels, which implies that the pre-tax wage for each individual will be unaffected by tax changes. Finally, we ignore the external costs of gasoline consumption. Incorporating such effects would raise the welfare estimates for all income groups (because the tax leads to reduced gasoline consumption), and might have important distributional effects if the external costs are unevenly distributed across income groups.

We consider three different assumptions about the revenue raised by the environmental tax: that it is discarded, that it is used to cut taxes on wage income, and that it is returned through a uniform lump-sum distribution. The first assumption implies that the net wage and lump-sum income for each household will remain constant: only the price of gasoline changes. The second assumption implies that net wages will rise, because the recycled revenue will lead to a drop in marginal tax rates. We assume that this is an equal percentage-point cut in all brackets (equivalent to a cut in the Medicare payroll tax, for example). The third assumption implies that household lump-sum income will rise. We assume that this transfer is based on the number of adults in a household; thus, a two-earner household will receive twice the transfer that a one-earner household would get. Under the latter two assumptions, the government budget constraint is given by

(10) $$G = \sum_i \sum_k \tau_i^k x_i^k - \sum_k T^k$$

where x_i^k is the consumption of good *i* by household *k*, τ_i^k is the tax rate on good *i* for household *k*, and T_i^k is the lump-sum transfer to household *k*. In each case, we calculate the demand for each good implied by a given income and vector of prices for each of the representative households, using the share equations (4a) and (4b). We then solve numerically for the tax cut or increase in the lump-sum transfer (depending on how the revenue is recycled) that will exactly offset the increased gas tax revenue.

We calculate incidence under three different welfare measures, each of which makes a different assumption about demand elasticities. The first assumes that all demand elasticities are zero. The second considers non-zero demand elasticities, but ignores cross-price elasticities. The third incorporates all of the estimated demand elasticities.

In each case, we still use the full system of demand elasticities to calculate the change in the labor tax rate or lump-sum transfer that is made possible by the increased gas tax revenue; thus, the change in the tax or transfer is the same across all three incidence measures. It is well-known that cross-price elasticities (and particularly the cross-price elasticity with leisure) play an essential role in determining the overall efficiency of a tax. Using the same tax and transfer changes for all three welfare measures minimizes the efficiency differences, allowing us to focus on how cross-price elasticities affect distribution.

Under the first assumption, we can calculate the incidence on each household as the sum over all goods of the price change for a given good times the household's consumption of that good.   Thus, the incidence on household *k* is given by

(11) $\sum_i \left(\bar{\tau}_i^k - \tau_i^k\right) x_i^k + T^k - \bar{T}^k$

Where $\bar{T}^k$ and $\bar{\tau}_i^k$ are the lump-sum transfer and vector of tax rates before the policy change, respectively.

For the second assumption, we calculate the partial-equilibrium change in consumer surplus for each market in which a price changes: the gas market in all cases, plus the labor market in the case in which we assume that the additional gas tax revenue is used to cut the tax on labor. Summing these consumer surplus changes and the change in income gives a measure of the change in welfare. This measure effectively ignores the effects of cross-price elasticities on the incidence of the tax. Thus, the incidence on household *k* is given by

(12) $$\Delta CS = \sum_i \left\{ \frac{x_i^k \bar{p}_i^k}{\varepsilon_i^k + 1} \left[1 - \left(\frac{p_i^k}{\bar{p}_i^k} \right)^{\varepsilon_i^k + 1} \right] \right\} + T^k - \bar{T}^k$$

where $\bar{\mathbf{p}}$ and $\mathbf{p}$ are the price vectors before and after the tax change, respectively, and ε_i is the compensated own-price elasticity of demand for good *i*.

Under the third assumption, we calculate incidence using the equivalent variation, which, for our assumed utility function, is

(13) $$EV = \bar{I} \exp\left\{ \beta_0 \prod_k^{n,l} \bar{p}_k^{\beta_k} \left[V(I, \mathbf{p}) - V(\bar{I}, \bar{\mathbf{p}}) \right] \right\} - \bar{I}$$

where $\bar{I}$ and I represent full income before and after the tax change, respectively, , and $V(I, \mathbf{p})$ is the indirect utility function, defined by

(14) $$V(I, \mathbf{p}) = \left[\ln I - \alpha_0 - \sum_k^{n,l} \alpha_k \ln p_k - \frac{1}{2} \sum_k^{n,l} \sum_j^{n,l} \gamma_{kj} \ln p_k \ln p_j \right] \Big/ \beta_0 \prod_k^{n,l} p_k^{\beta_k}$$

Comparing these incidence estimates across different income groups will demonstrate how regressive or progressive a particular tax shift is. Comparisons across the three different welfare measures will illustrate the importance (or lack thereof) of incorporating behavioral changes in incidence estimates.

B. Incidence Results

Table 4 presents the results of the incidence analysis. For each of the three assumptions about the use of the additional revenue from the increased gas tax, it shows the welfare change for each income quintile as a percentage of total expenditure for that quintile, under each of the three different welfare measures.

The table shows that increasing the gas tax will generally be regressive, but that the revenue can be return in such a way as to change this result. If the revenue is simply discarded, then the welfare cost as a fraction of expenditure is lower for higher-income groups. The cost to the first quintile, as a fraction of expenditure, is roughly 2.5 times that for the top quintile. This is not surprising; numerous studies have shown that gasoline has a larger budget share for lower-income groups, and thus that the gas tax tends to be regressive.

If the revenue is used to cut the labor tax, all five quintiles are substantially better off than when the revenue is discarded, but the general pattern of regressivity is similar. Lowering the labor tax provides a larger benefit for higher-income households, and thus it does nothing to offset the regressivity of the increased gas tax.

However, when the revenue is used to provide a lump-sum transfer to households, the pattern is different. The bottom quintile is actually better off as a result of the change, even though our estimates ignore the external benefits of reduced gas consumption. In this case, the increased transfer they receive more than offsets the higher price of gasoline. For the other four quintiles, however, the effect of the higher gas price dominates, and so those households are made worse off. In this case, the welfare cost as a fraction of expenditures is highest for the third and fourth quintiles; the lower quintiles do relatively well because of the progressive lump-sum transfer, and the gas share for the top quintile is small enough that even though that quintile's relative benefit from the lump-sum transfer is small, it still does better than the middle-income groups.

Comparing the incidence measure that assumes no change in demand to either of the other measures shows that demand responses are somewhat important; in all cases, the measured welfare cost is significantly lower when such responses are taken into account. Given the magnitude of the tax change involved, this is hardly surprising; households will consume significantly less gasoline in response to such a large tax increase, and that reduces the burden of the tax increase somewhat.

However, incorporating demand responses makes the gas tax look only very slightly more progressive. Own-price gas demand elasticities are relatively similar across income quintiles, so incorporating demand responses has a similar effect on the tax burden for all quintiles. The one exception is that gas demand is substantially less elastic for the top quintile than for the other four, so the relative burden on the top quintile is larger under measures that include demand responses.

Comparing the partial-equilibrium consumer surplus measure to the full equivalent variation shows that including cross-price effects in the welfare measure has little effect; these two measures yield very similar results. Even for the large price changes considered here, cross-price effects on demand are sufficiently weak that taking them into account makes little difference in the incidence analysis.

There is an important caveat to that result, however; even for the consumer surplus measure, the change in the labor tax or lump-sum transfer was still calculated using a demand system that includes cross-price effects. If cross-price effects were ignored there, then the change in the labor tax or lump-sum transfer would be significantly different. As is clear from the table, the tax rate and transfer amount play an important role, affecting both the overall welfare gain and the relative standing of the different quintiles. In essence, cross-price effects are important for the overall efficiency of the policy, and so they can be important for distributional analysis even though they do not directly affect the incidence of a particular set of tax and transfer changes.

IV. Conclusion

This paper has analyzed the distributional effects of increasing the gasoline tax, under a range of assumptions about how the revenue is recycled and for a range of different welfare measures. It shows that increasing the gasoline tax will generally be regressive, though it can become somewhat progressive if the additional revenue is used to provide a lump-sum transfer to households; the progressivity of the transfer slightly outweighs the regressivity of the tax increase.

Incorporating demand responses into our incidence calculations results in significantly lower estimates of the tax burden on all groups, because gas consumption falls substantially in response to the increased tax. This has little effect on the relative burden on different income groups, though. While the top quntile has a substantially lower gas demand elasticity, so incorporating demand responses makes the tax change appear slightly more progressive, the effect is small because gas demand elasticities are similar for the other four quintiles.

For a given set of tax rate and transfer changes, calculating incidence using a welfare measure that incorporates cross-price elasticities makes almost no difference. However, this does not necessarily mean that cross-price elasticities are unimportant for distributional analysis, because when the gas tax revenue is recycled to lower another tax rate or provide a lump-sum transfer, such cross-price elasticities play an important role in determining the change in the tax rate or transfer amount. Or, in other words, because cross-price elasticities affect the efficiency of a particular tax change, they can be important for distributional analysis even though their direct effect on incidence is insignificant.

Table 1: Summary Statistics for the Workers in One-Earner Households

Variable	**Mean**	**Standard Deviation**
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
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^2)	235.05	555.69
State Unemployment Rate (%)	4.95	1.14

Table 2: Summary Statistics for Workers in Two-Earner Households

Variable	Mean	Standard Deviation
Gasoline per Week (gallons)	26.92	18.61
Male Hours per Week	41.37	11.45
Female Hours per Week	40.03	23.82
Gasoline Share of Expenditures	.02	.01
Male Leisure Share of Expenditures	.27	.17
Female Leisure Share of Expenditures	.27	.17
Other Good Share of Expenditures	.44	.13
Gas Price ($)	1.19	.11
Other Good Price (index)	103.60	10.55
Male Net Wage ($)	11.08	3.16
Female Net Wage ($)	8.60	2.27
ln(y/P)	3.62	.94
Male Education		
Less than High School Diploma (%)	8.0	-
High School Diploma (%)	27.0	-
More than High School Diploma (%)	65.0	-
Female Education		
Less than High School Diploma (%)	7.0	-
High School Diploma (%)	28.0	-
More than High School Diploma (%)	65.0	-
Race of Household Head		
White (%)	89.0	-
Black (%)	7.0	-
Asian (%)	1.0	-
Other race (%)	3.0	-
Number of Kids	.48	.82
Region		
Northeast (%)	16.0	-
Midwest (%)	25.0	-
South (%)	34.0	-
West (%)	25.0	-
Number of Vehicles	2.46	1.59
State Average Drive Time to Work (minutes)	22.09	2.83
State Population Density (persons/mile^2)	217.94	388.09
State Unemployment Rate (%)	4.89	1.09

Table 3: Estimated Elasticities by Quintile

Quintile 1

Compensated Price Elasticities			
	Gas Price	Wage	Other Good Price
Gasoline	-0.651	0.061	0.590
Leisure	0.002	0.025	-0.071
Other Good	0.037	-0.062	0.025
Uncompensated Price Elasticities			
	Gas Price	Wage	Other Good Price
Gasoline	-0.666	0.463	0.358
Leisure	-0.020	0.626	-0.115
Other Good	0.028	0.184	-0.104

Quintile 2

Compensated Price Elasticities			
	Gas Price	Wage	Other Good Price
Gasoline	-0.768	-0.088	0.856
Leisure	-0.002	0.000	-0.005
Other Good	0.048	0.012	-0.060
Uncompensated Price Elasticities			
	Gas Price	Wage	Other Good Price
Gasoline	-0.785	0.357	0.537
Leisure	-0.026	0.616	0.008
Other Good	0.035	0.354	-0.293

Quintile 3

Compensated Price Elasticities			
	Gas Price	Wage	Other Good Price
Gasoline	-0.674	-0.063	0.737
Leisure	-0.002	-0.020	-0.027
Other Good	0.037	0.041	-0.079
Uncompensated Price Elasticities			
	Gas Price	Wage	Other Good Price
Gasoline	-0.693	0.385	0.368
Leisure	-0.027	0.573	-0.002
Other Good	0.023	0.390	-0.360

Quintile 4

Compensated Price Elasticities			
	Gas Price	Wage	Other Good Price
Gasoline	-0.757	-0.016	0.773
Leisure	-0.001	-0.175	-0.172
Other Good	0.033	0.215	-0.248
Uncompensated Price Elasticities			
	Gas Price	Wage	Other Good Price
Gasoline	-0.775	0.407	0.355
Leisure	-0.025	0.402	-0.130
Other Good	0.018	0.565	-0.587

Quintile 5

Compensated Price Elasticities			
	Gas Price	Wage	Other Good Price
Gasoline	-0.322	0.209	0.114
Leisure	0.008	-0.334	-0.085
Other Good	0.003	0.211	-0.214
Uncompensated Price Elasticities			
	Gas Price	Wage	Other Good Price
Gasoline	-0.337	0.558	-0.463
Leisure	-0.009	0.080	-0.103
Other Good	-0.011	0.545	-0.767

Table 4: Incidence of an Increased Gas Tax

		Quintile 1	2	3	4	5
Additional gas tax revenue discarded	Equivalent Variation	-2.46%	-2.15%	-1.95%	-1.62%	-1.05%
	Partial Equilibrium Consumer Surplus	-2.48%	-2.18%	-1.97%	-1.64%	-1.07%
	No Demand Response	-2.84%	-2.54%	-2.27%	-1.91%	-1.14%
Additional gas tax revenue used to cut labor tax rate	Equivalent Variation	-0.56%	-0.41%	-0.42%	-0.24%	-0.18%
	Partial Equilibrium Consumer Surplus	-0.58%	-0.44%	-0.43%	-0.24%	-0.19%
	No Demand Response	-0.94%	-0.80%	-0.72%	-0.52%	-0.26%
Additional gas tax revenue used to provide lump-sum transfer to households	Equivalent Variation	0.43%	-0.26%	-0.51%	-0.53%	-0.46%
	Partial Equilibrium Consumer Surplus	0.42%	-0.27%	-0.52%	-0.53%	-0.48%
	No Demand Response	0.06%	-0.63%	-0.81%	-0.81%	-0.55%

Gas tax increased to $0.95/gallon in all cases

Each welfare measure expressed as a percentage of expenditures

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Appendix

Table A-1: One-adult Household Regression Results by Quintile

	Quintile 1		*Quintile 2*	
	gasshare	leisshare	gasshare	leisshare
ln(gasprice)	0.0092	-0.0083	-0.0116	-0.0084
	(0.0061)	(0.0039)	(0.0069)	(0.0041)
ln(wage)	-0.0083	0.0518	-0.0084	0.0973
	(0.0039)	(0.0158)	(0.0041)	(0.0078)
ln(other good price)	-0.0009	-0.0436	0.0200	-0.0889
	(0.0070)	(0.0151)	(0.0071)	(0.0065)
ln(y/P)	-0.0036	0.2779	0.0030	0.2373
	(0.0013)	(0.0053)	(0.0020)	(0.0038)
Age	0.0002	-0.0024	0.0000	-0.0001
	(0.0004)	(0.0015)	(0.0004)	(0.0008)
Age Squared	-0.000004	0.000028	-0.000001	0.000004
	(0.000004)	(0.000017)	(0.000005)	(0.000010)
High School Degree	-0.0068	0.0111	-0.0043	0.0067
	(0.0016)	(0.0064)	(0.0024)	(0.0044)
More than HS Degree	-0.0089	0.0170	-0.0068	0.0056
	(0.0020)	(0.0081)	(0.0027)	(0.0050)
Black	0.0025	-0.0298	0.0021	-0.0082
	(0.0014)	(0.0055)	(0.0018)	(0.0033)
Asian	0.0104	0.0039	0.0007	-0.0274
	(0.0047)	(0.0188)	(0.0073)	(0.0136)
Other Race	0.0090	-0.0433	-0.0019	0.0095
	(0.0032)	(0.0126)	(0.0038)	(0.0070)
Female	-0.0045	-0.0067	-0.0036	-0.0023
	(0.0012)	(0.0048)	(0.0014)	(0.0026)
Number of Kids	-0.0006	-0.0259	-0.0002	-0.0529
	(0.0005)	(0.0019)	(0.0008)	(0.0016)
Number of Vehicles	0.0019	0.0089	0.0037	-0.0064
	(0.0011)	(0.0043)	(0.0008)	(0.0016)
State Average Drive Time	0.0009	-0.0005	0.0014	-0.0039
	(0.0007)	(0.0026)	(0.0007)	(0.0014)
State Population Density	-0.0000	0.0001	-0.0001	0.0002
	(0.0000)	(0.0001)	(0.0000)	(0.0001)
State Unemp. Rate	0.0007	0.0002	0.0001	0.0027
	(0.0009)	(0.0035)	(0.0011)	(0.0021)
Inverse Mills Ratio (gas)	-0.0203	0.0936	-0.0096	0.0132
	(0.0024)	(0.0097)	(0.0030)	(0.0056)
Constant	0.0426	-0.2016	-0.0795	0.0033
	(0.0331)	(0.0807)	(0.0350)	(0.0405)
Observations	1178	1178	803	803

Three-stage least squares regressions, occupation instruments for ln(wage).
All regressions also include state dummy variables.
Standard errors in parentheses.

Table A-1: One-adult Household Regression Results by Quintile (continued)

	Quintile 3		*Quintile 4*		*Quintile 5*	
	gasshare	leisshare	gasshare	leisshare	gasshare	leisshare
ln(gasprice)	0.0002	-0.0144	0.0078	-0.0110	-0.0058	0.0007
	(0.0073)	(0.0038)	(0.0075)	(0.0035)	(0.0094)	(0.0046)
ln(wage)	-0.0144	0.1067	-0.0110	0.0919	0.0007	0.0860
	(0.0038)	(0.0073)	(0.0035)	(0.0086)	(0.0046)	(0.0284)
ln(other good price)	0.0142	-0.0923	0.0032	-0.0809	0.0051	-0.0866
	(0.0074)	(0.0057)	(0.0079)	(0.0077)	(0.0103)	(0.0291)
ln(y/P)	0.0019	0.2425	0.0027	0.2527	-0.0023	0.1320
	(0.0023)	(0.0042)	(0.0022)	(0.0053)	(0.0026)	(0.0165)
Age	0.0000	0.0010	0.0000	0.0004	0.0009	-0.0004
	(0.0005)	(0.0009)	(0.0005)	(0.0012)	(0.0006)	(0.0035)
Age Squared	0.000001	-0.000014	-0.000000	-0.000005	-0.000012	0.000025
	(0.000006)	(0.000010)	(0.000006)	(0.000014)	(0.000006)	(0.000040)
High School Degree	-0.0049	0.0066	-0.0006	0.0092	0.0023	-0.0101
	(0.0035)	(0.0066)	(0.0032)	(0.0075)	(0.0045)	(0.0280)
More than HS Degree	-0.0039	0.0061	-0.0026	0.0151	0.0008	0.0043
	(0.0036)	(0.0066)	(0.0032)	(0.0076)	(0.0046)	(0.0288)
Black	0.0002	-0.0021	0.0021	-0.0026	-0.0006	0.0136
	(0.0019)	(0.0035)	(0.0020)	(0.0049)	(0.0023)	(0.0143)
Asian	-0.0067	0.0211	-0.0040	0.0151	-0.0098	0.0325
	(0.0063)	(0.0118)	(0.0069)	(0.0166)	(0.0101)	(0.0631)
Other Race	0.0017	-0.0021	0.0022	-0.0069	-0.0031	0.0109
	(0.0036)	(0.0066)	(0.0030)	(0.0073)	(0.0037)	(0.0229)
Female	-0.0033	0.0019	-0.0043	0.0053	-0.0029	0.0019
	(0.0014)	(0.0026)	(0.0013)	(0.0032)	(0.0015)	(0.0095)
Number of Kids	0.0006	-0.0638	-0.0022	-0.0643	-0.0026	-0.0489
	(0.0010)	(0.0018)	(0.0011)	(0.0026)	(0.0015)	(0.0092)
Number of Vehicles	0.0029	-0.0032	0.0011	-0.0021	0.0022	-0.0141
	(0.0009)	(0.0016)	(0.0007)	(0.0017)	(0.0006)	(0.0040)
State Average Drive Time	0.0009	-0.0076	0.0012	-0.0098	0.0012	0.0017
	(0.0010)	(0.0018)	(0.0009)	(0.0021)	(0.0012)	(0.0076)
State Population Density	-0.0000	0.0003	-0.0001	0.0003	-0.0001	-0.0002
	(0.0000)	(0.0001)	(0.0000)	(0.0001)	(0.0001)	(0.0004)
State Unemp. Rate	-0.0007	0.0042	0.0018	0.0023	0.0013	-0.0025
	(0.0012)	(0.0022)	(0.0010)	(0.0025)	(0.0013)	(0.0078)
Inverse Mills Ratio (gas)	-0.0089	0.0101	-0.0097	0.0261	-0.0016	0.0300
	(0.0033)	(0.0062)	(0.0032)	(0.0076)	(0.0037)	(0.0232)
Constant	-0.0327	-0.0373	-0.0045	-0.1181	-0.0466	0.0021
	(0.0383)	(0.0451)	(0.0410)	(0.0577)	(0.0516)	(0.2021)
Observations	635	635	539	539	478	478

Three-stage least squares regressions, occupation instruments for ln(wage).
All regressions also include state dummy variables.
Standard errors in parentheses.

Table A-2: Two-adult Household Regression Results by Quintile

	Quintile 1			*Quintile 2*		
	gasshare	Male leisshare	Female leisshare	gasshare	Male leisshare	Female leisshare
ln(gasprice)	0.0033	-0.0053	-0.0053	0.0101	-0.0080	-0.0080
	(0.0053)	(0.0018)	(0.0018)	(0.0049)	(0.0013)	(0.0014)
ln(male wage)	-0.0053	0.0969	-0.0313	-0.0080	0.0871	-0.0074
	(0.0018)	(0.0077)	(0.0037)	(0.0013)	(0.0045)	(0.0019)
ln(female wage)	-0.0053	-0.0313	0.1078	-0.0080	-0.0074	0.1155
	(0.0018)	(0.0037)	(0.0070)	(0.0014)	(0.0019)	(0.0041)
ln(other good price)	0.0073	-0.0604	-0.0713	0.0059	-0.0717	-0.1001
	(0.0059)	(0.0105)	(0.0101)	(0.0053)	(0.0057)	(0.0055)
ln(y/P)	-0.0033	0.0277	0.0262	-0.0046	0.0359	0.0407
	(0.0011)	(0.0048)	(0.0044)	(0.0009)	(0.0032)	(0.0029)
Age	0.0002	-0.0002	-0.0013	0.0002	0.0008	-0.0023
	(0.0003)	(0.0006)	(0.0005)	(0.0003)	(0.0004)	(0.0003)
Age Squared	-0.000003	0.000006	0.000012	-0.000002	0.000002	0.000019
	(0.000003)	(0.000004)	(0.000003)	(0.000003)	(0.000003)	(0.000002)
High School Degree	-0.0002	0.0015	-0.0077	-0.0004	0.0125	-0.0045
	(0.0010)	(0.0053)	(0.0037)	(0.0013)	(0.0044)	(0.0038)
More than HS Degree	-0.0011	0.0023	0.0047	-0.0001	0.0162	-0.0022
	(0.0013)	(0.0065)	(0.0052)	(0.0015)	(0.0051)	(0.0045)
Black	0.0010	-0.0021	-0.0062	0.0003	-0.0062	0.0128
	(0.0014)	(0.0060)	(0.0042)	(0.0013)	(0.0042)	(0.0033)
Asian	0.0023	0.0070	-0.0153	-0.0016	0.0236	0.0002
	(0.0037)	(0.0179)	(0.0103)	(0.0040)	(0.0128)	(0.0091)
Other Race	0.0054	-0.0147	0.0102	0.0006	0.0330	-0.0015
	(0.0047)	(0.0126)	(0.0148)	(0.0042)	(0.0091)	(0.0084)
Number of Kids	0.0002	-0.0146	-0.0108	0.0007	-0.0233	-0.0115
	(0.0004)	(0.0022)	(0.0020)	(0.0004)	(0.0018)	(0.0015)
Number of Vehicles	0.0027	-0.0053	-0.0069	0.0017	-0.0072	0.0007
	(0.0006)	(0.0024)	(0.0024)	(0.0004)	(0.0016)	(0.0013)
State Avg. Drive Time	0.0016	-0.0016	0.0008	0.0015	-0.0055	-0.0038
	(0.0005)	(0.0030)	(0.0027)	(0.0005)	(0.0021)	(0.0018)
State Population Density	-0.0000	-0.0003	0.0002	-0.0001	0.0001	0.0002
	(0.0000)	(0.0002)	(0.0001)	(0.0000)	(0.0001)	(0.0001)
State Unemp. Rate	-0.0004	-0.0006	-0.0034	-0.0012	0.0099	-0.0061
	(0.0009)	(0.0045)	(0.0041)	(0.0007)	(0.0032)	(0.0028)
Inverse Mills Ratio (gas)	-0.0246	-0.0824	0.0297	-0.0041	-0.1438	0.0075
	(0.0140)	(0.0443)	(0.0460)	(0.0133)	(0.0344)	(0.0289)
Constant	-0.0152	0.4894	0.4415	0.0144	0.4166	0.5196
	(0.0250)	(0.0616)	(0.0567)	(0.0227)	(0.0417)	(0.0358)
Observations	802	802	802	1178	1178	1178

Three-stage least squares regressions, occupation instruments for ln(wage).
All regressions also include state dummy variables.
Standard errors in parentheses.

Table A-2: Two-adult Household Regression Results by Quintile (Continued)

	Quintile 3			*Quintile 4*		
	gasshare	Male leisshare	Female leisshare	gasshare	Male leisshare	Female leisshare
ln(gasprice)	0.0078	-0.0060	-0.0063	0.0036	-0.0048	-0.0051
	(0.0046)	(0.0011)	(0.0012)	(0.0036)	(0.0009)	(0.0010)
ln(male wage)	-0.0060	0.0913	-0.0036	-0.0048	0.0858	0.0012
	(0.0011)	(0.0038)	(0.0018)	(0.0009)	(0.0039)	(0.0018)
ln(female wage)	-0.0063	-0.0036	0.0975	-0.0051	0.0012	0.0848
	(0.0012)	(0.0018)	(0.0039)	(0.0010)	(0.0018)	(0.0040)
ln(other good price)	0.0045	-0.0816	-0.0876	0.0064	-0.0822	-0.0809
	(0.0051)	(0.0050)	(0.0052)	(0.0038)	(0.0049)	(0.0052)
ln(y/P)	-0.0027	0.0481	0.0335	-0.0028	0.0507	0.0362
	(0.0008)	(0.0031)	(0.0028)	(0.0007)	(0.0033)	(0.0031)
Age	0.0007	-0.0008	-0.0009	0.0007	-0.0011	-0.0004
	(0.0002)	(0.0003)	(0.0003)	(0.0002)	(0.0003)	(0.0003)
Age Squared	-0.000008	0.000012	0.000011	-0.000008	0.000012	0.000008
	(0.000003)	(0.000002)	(0.000002)	(0.000003)	(0.000002)	(0.000002)
High School Degree	-0.0012	0.0017	-0.0061	-0.0031	0.0054	-0.0156
	(0.0014)	(0.0044)	(0.0047)	(0.0015)	(0.0065)	(0.0057)
More than HS Degree	-0.0011	0.0067	0.0016	-0.0017	0.0108	-0.0073
	(0.0015)	(0.0049)	(0.0053)	(0.0015)	(0.0068)	(0.0063)
Black	-0.0002	-0.0150	0.0035	0.0016	0.0032	-0.0062
	(0.0014)	(0.0047)	(0.0039)	(0.0013)	(0.0046)	(0.0046)
Asian	0.0000	-0.0043	-0.0075	0.0105	0.0047	-0.0245
	(0.0041)	(0.0100)	(0.0133)	(0.0036)	(0.0115)	(0.0180)
Other Race	0.0044	0.0049	0.0123	0.0005	0.0248	0.0044
	(0.0037)	(0.0096)	(0.0076)	(0.0031)	(0.0092)	(0.0086)
Number of Kids	0.0003	-0.0256	-0.0125	-0.0007	-0.0230	-0.0134
	(0.0004)	(0.0017)	(0.0015)	(0.0004)	(0.0018)	(0.0017)
Number of Vehicles	0.0013	-0.0025	-0.0014	0.0013	-0.0019	-0.0019
	(0.0003)	(0.0011)	(0.0010)	(0.0003)	(0.0012)	(0.0011)
State Avg. Drive Time	0.0010	0.0010	-0.0054	0.0005	-0.0041	-0.0026
	(0.0004)	(0.0018)	(0.0016)	(0.0004)	(0.0018)	(0.0017)
State Population Density	-0.0000	-0.0001	0.0001	-0.0000	0.0001	0.0001
	(0.0000)	(0.0001)	(0.0001)	(0.0000)	(0.0001)	(0.0001)
State Unemp. Rate	-0.0004	-0.0007	0.0014	0.0004	0.0011	0.0028
	(0.0006)	(0.0027)	(0.0024)	(0.0005)	(0.0025)	(0.0023)
Inverse Mills Ratio (gas)	-0.0127	-0.0637	-0.0743	-0.0048	-0.1158	0.0062
	(0.0110)	(0.0311)	(0.0288)	(0.0100)	(0.0316)	(0.0313)
Constant	0.0031	0.3051	0.4808	-0.0000	0.3616	0.3263
	(0.0220)	(0.0349)	(0.0314)	(0.0178)	(0.0378)	(0.0359)
Observations	1346	1346	1346	1442	1442	1442

Three-stage least squares regressions, occupation instruments for ln(wage).
All regressions also include state dummy variables.
Standard errors in parentheses.

Table A-2: Two-adult Household Regression Results by Quintile (Continued)

	Quintile 5		
	gasshare	Male leisshare	Female leisshare
ln(gasprice)	0.0130	-0.0013	-0.0012
	(0.0035)	(0.0008)	(0.0009)
ln(male wage)	-0.0013	0.0494	-0.0043
	(0.0008)	(0.0056)	(0.0027)
ln(female wage)	-0.0012	-0.0043	0.0515
	(0.0009)	(0.0027)	(0.0059)
ln(other good price)	-0.0106	-0.0438	-0.0460
	(0.0038)	(0.0075)	(0.0077)
ln(y/P)	-0.0003	0.0133	0.0194
	(0.0008)	(0.0054)	(0.0047)
Age	0.0003	0.0009	-0.0001
	(0.0002)	(0.0004)	(0.0003)
Age Squared	-0.000003	-0.000004	0.000003
	(0.000002)	(0.000003)	(0.000002)
High School Degree	0.0012	0.0070	0.0031
	(0.0018)	(0.0096)	(0.0111)
More than HS Degree	0.0007	0.0208	0.0182
	(0.0019)	(0.0102)	(0.0122)
Black	-0.0009	-0.0093	-0.0140
	(0.0013)	(0.0078)	(0.0066)
Asian	0.0089	0.0172	-0.0162
	(0.0030)	(0.0185)	(0.0158)
Other Race	-0.0061	-0.0414	-0.0502
	(0.0023)	(0.0093)	(0.0088)
Number of Kids	-0.0007	-0.0149	-0.0071
	(0.0004)	(0.0027)	(0.0024)
Number of Vehicles	0.0010	0.0029	0.0049
	(0.0002)	(0.0012)	(0.0011)
State Avg. Drive Time	0.0007	0.0027	-0.0045
	(0.0004)	(0.0026)	(0.0023)
State Population Density	-0.0000	-0.0000	0.0003
	(0.0000)	(0.0001)	(0.0001)
State Unemp. Rate	-0.0003	0.0017	0.0076
	(0.0005)	(0.0030)	(0.0027)
Inverse Mills Ratio (gas)	0.0220	0.2677	0.2986
	(0.0081)	(0.0345)	(0.0331)
Constant	0.0392	0.0744	0.1528
	(0.0177)	(0.0519)	(0.0493)
Observations	1502	1502	1502

Three-stage least squares regressions, occupation instruments for ln(wage).
All regressions also include state dummy variables.
Standard errors in parentheses.