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ESTIMATES FROM A CONSUMER DEMAND SYSTEM: IMPLICATIONS FOR THE INCIDENCE OF ENVIRONMENTAL TAXES

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ABSTRACT

Most studies suggest that environmental taxes are regressive, and thus are unattractive policy options. We consider the distributional effects of a gasoline tax increase using three welfare measures and under three scenarios for gas tax revenue use. To incorporate behavioral responses we use Consumer Expenditure Survey data to estimate a consumer demand system that includes gasoline, other goods, and leisure. We find that the gas tax is regressive, but that returning the revenue through a lump-sum transfer more than offsets this, yielding a net increase in progressivity. We also find that ignoring behavioral changes in distributional calculations overstates both the overall burden of the tax and its regressivity.

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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. In this paper, we consider the distributional effects of a gasoline tax increase. The gasoline tax's regressivity is often cited as one of the strongest arguments against increasing this tax. We show, however, that increasing the gas tax does not have to be regressive; the revenue can be used to achieve a net gain in progressivity, though this does come at a significant efficiency cost.

Our study makes three main contributions. First, we examine the importance of considering behavioral effects in calculating the incidence of environmental taxes. Many find that because gasoline has an income elasticity of less than one, taxes on gasoline would be regressive (see for example Kayser [11], Poterba [16], Sevigny [17], Sipes and Mendelsohn [19], and Walls *et al.* [22]). These studies provide evidence on the distributional effects of gasoline taxes holding household behavior constant, or assuming that all households have the same degree of price responsiveness.[2]

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 nearly double the price of gasoline. With tax changes of this magnitude, even if demand is relatively 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. For example, because poor households have smaller budgets, they may be more responsive to prices than the wealthy. On the other hand, if poor people have fewer transportation options, they may be less price-responsive. 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.

Second, this paper considers three scenarios for gas tax revenue use: 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 scenario implies that the net wage and lump-sum income for each household will remain constant: only the price of gasoline changes. The second scenario implies that net wages will rise, because the recycled revenue will lead to a drop in marginal tax rates. The third scenario implies that household lump-sum income will rise.[3] Discarding the revenue is useful as a benchmark, as it isolates the distributional effect of the gas tax itself. Using the revenue to lower the tax rate on wages is a policy designed to be efficient, with no concern for distributional issues. Most recent studies of second-best optimal environmental taxes assume that revenue is returned in this fashion (see, for example, West and Williams [24] or Parry and Small [15]). Finally, returning the revenue through a lump-sum transfer yields a more progressive distributional effect.

Third, this paper 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 [2], explicitly 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. However, given the importance of cross-price elasticities in other contexts (the efficiency of taxation, for example), it is 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.[4]

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 these issues by using the Almost Ideal Demand System (AIDS) first derived by Deaton and Muellbauer [6]. 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 and for different income quintiles within each group.

We find that increasing the gas tax is generally regressive, but that this depends greatly on how the revenue is used; using the additional revenue to provide a lump-sum transfer to households more than offsets the regressivity of the gas tax, and thus in this case, increasing the gas tax is quite progressive. In contrast, using the revenue to cut the tax on labor income yields an efficiency gain, but does little to offset–and may in fact exacerbate–the regressivity of the gas tax.

Incorporating demand responses is important for measuring both the overall burden and the distribution of that burden. Ignoring such demand responses raises the measured welfare cost significantly for all income groups, but this effect is much weaker for the top quintile than for the rest of the income distribution. Thus, studies that do not consider demand responses will substantially overstate the regressivity of the gas tax. 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 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 [24], 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 [6]. 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 [13, 14]:

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

where y is total income, the amount spent on gasoline, other goods, and leisure, 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-adult households have one leisure share equation (4b) for the household's male adult and another for the household's female adult.

Provided that these restrictions hold, (4) represents a system of demand functions that add up to total income, are homogeneous of degree zero in prices and total income, 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 (4) 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, [8]). Then, since we do not observe wages for individuals who are not working, we follow Heckman [9] 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 (where an adult is at least 18 years of age). 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-adult and two-adult samples of workers. The one-adult sample of workers contains 3633 households; the two-adult sample contains 6270 households.

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 net wage in the one-adult sample is $9.73 per hour. Males in the two-adult sample make $11.08 per hour, while women make $8.60 per hour. The overall wage distribution in our sample closely follows the wage distribution in the 1997 Current Population Survey.

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.[5]

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.[6]

Before we divide households into quintiles, we use an equivalence scale to adjust total expenditures on gasoline and other goods 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 on gasoline and other goods by $(\mathit{adults} + \mathit{children})^{.5}$. We pool one-adult and two-adult households, rank them together by equivalence-scale adjusted total expenditures on gasoline and other goods, and divide them into quintiles.[7]

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 plus 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-stage least squares. We include in each system member and household characteristics that may affect gasoline or leisure shares: the members' age, age squared, race, sex (in the case of one-adult households only), education, number of children, and number of vehicles. 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, evaluated using by quintile means.[8] These elasticity estimates aggregate together male and female leisure for two-adult households, and then aggregate together the one-adult and two-adult 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 -0.5 (two-adult households) to -0.7, except for the top quintile, and fall in the span of estimates reported in gas demand survey articles. The top quintile is substantially less responsive to increases in the price of gasoline, with own-price gas demand elasticities of roughly -0.3.[9]

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 from its current level (which averages roughly 37 cents per gallon: the 18.4 cent federal gas tax plus the average state gas tax) to $1.39 per gallon.[10] This is the optimal second-best gas tax found by West and Williams [24], based on demand system estimates similar to those in the present paper, but with a representative agent model. That study in turn used an estimate of 83 cents for the marginal external damage per gallon of gasoline, which was taken from a survey by Parry and Small [15]. 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.[11] 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-adult household will receive twice the transfer that a one-adult household would get. Under the latter two assumptions, the government budget constraint is given by

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

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

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

Where $\bar{T}^k$ and $\bar{\tau}_i^k$ are the lump-sum transfer and vector of tax rates before the policy change, respectively. This is simply the net change in tax payments that results from the change in taxes and transfers.

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

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

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*.[12]

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

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

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,[13] defined by

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

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 (on gasoline and other goods) for that quintile, under each of the three different welfare measures. The table also provides the aggregate burden–the sum of the burden across all five quintiles, divided by the sum of expenditures–from the tax change, thus allowing a comparison of overall efficiency across the three uses for the additional revenue.

Finally, the table lists the Suits index for each case, which is a measure of the progressivity or regressivity of the tax change. The Suits index is given by

$$(15) \quad S = 1 - \sum_{i=1}^{5} \left(T_i + T_{i-1}\right)\left(y_i - y_{i-1}\right)$$

where $T_i = \sum_{j=1}^{i} t_j$ and where y_i and t_i are quintile *i*'s shares of total expenditure and of the burden of the tax, respectively.[14] This measure is analogous to the Gini coefficient, and can range from –1 (if the entire burden of a new tax is borne by those with the lowest incomes) to 1 (if the entire burden is borne by those with the highest incomes). The Suits index is usually calculated using the change in tax paid–equivalent to our equation (11)–as the measure of the tax burden, but can also be calculated using other measures, as we do here. See Suits [20] for more detail on this index.

The table shows that increasing the gas tax will generally be regressive, but that the revenue can be returned 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 more than twice that for the top quintile. The Suits index for this case is roughly –0.16. As a comparison, the Suits index for the taxes considered by Suits [20] ranged from –0.17 to 0.36, so the regressivity of the gas tax is similar to that of the most regressive tax (the payroll tax) considered in that study. 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. Indeed, this is the most efficient of the three options considered for how to use the gas tax revenue; cutting the labor tax rate reduces the deadweight loss in the labor market. However, the general pattern of regressivity remains. The Suits index even falls slightly, suggesting that this use of the revenue makes the change very slightly more regressive.[15] 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. The Suits index is roughly 0.14, indicating that this tax change is progressive overall; the increased lump-sum transfer is sufficiently progressive to overcome the regressivity of the gas tax.

This policy is less efficient than using the revenue to cut the labor tax rate; the overall welfare difference between the two policies is 0.1% of expenditures. This cost is relatively small in absolute terms, but is substantial relative to the distributional effects. Using the revenue for a lump-sum transfer rather than for a cut in the labor tax makes the average household in one of the bottom two quintiles better off by $143 per year, but at an average cost of $229 to the households in the top two quintiles.

Comparing the incidence measure that assumes no change in demand to either of the other measures shows that considering demand responses is important for measuring either the overall burden of the tax or the distribution of that burden. Omitting demand responses will lead one to substantially overstate the welfare cost of the gas tax. 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.

Omitting demand responses also makes the gas tax appear more regressive. Own-price gas demand elasticities are relatively similar across most of the income distribution, but gas demand for the top quintile is substantially less elastic. Thus, the relative burden on the top quintile is larger under measures that include demand responses, making the tax more progressive. This effect can be substantial; a gas tax increase with the revenue used to provide a lump-sum transfer appears to be slightly regressive (Suits index=-0.046) when demand responses are ignored, but including demand responses shows that this case is actually quite progressive (Suits index=0.14). A similar, though less dramatic, pattern appears when the tax revenue is discarded or used to cut the labor tax.

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; for the gas tax change we consider, the changes in the labor tax rate or lump-sum transfer predicted by a partial-equilibrium model would be just over half as large as those predicted by the general-equilibrium model, whereas the changes that would be predicted if behavioral changes were ignored would be nearly twice as large. 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.

Our use of Consumer Expenditure Survey data and estimation of the almost-ideal demand system allows us to incorporate behavioral responses, including cross-price effects, in our incidence calculations. Similar data and techniques could be used to examine the incidence of other environmental taxes across income groups, regions, or urban versus rural households.

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. It has little effect, however, on the relative burden on different income groups, though. While the top quintile 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, such cross-price elasticities may still affect incidence, because they play an important role in determining the changes in other tax rates or transfers made possible by the gas tax revenue. 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.

Furthermore, even our partial-equilibrium calculations used elasticity estimates from a demand system that does not impose separability. It might be valuable for future research to compare these results to a demand system that imposes separability in the estimation, such as the linear expenditure system.

Table 1: Summary Statistics for Workers in One-Adult Households

Variable	Mean	Standard Deviation
Gasoline per Week (gallons)	12.07	11.82
Hours per Week	40.36	11.90
Gasoline Share of Expenditures	.02	.02
Leisure Share of Expenditures	.52	.16
Other Good Share of Expenditures	.47	.16
Gas Price ($)	1.19	.11
Other Good Price (index)	103.99	10.51
Net Wage ($)	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 (%)	80.0	-
Black (%)	16.0	-
Asian (%)	1.0	-
Other race (%)	3.0	-
Female (%)	56.00	-
Number of Kids	.42	.90
Region		
Northeast (%)	15.0	-
Midwest (%)	24.0	-
South (%)	32.0	-
West (%)	28.0	-
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
Observations	3633	-

Table 2: Summary Statistics for Workers in Two-Adult 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
Observations	6270	-

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

Additional gas tax revenue discarded:

	Quintile 1	2	3	4	5	Aggregate Tax Burden	Suits Index
Equivalent Variation	-3.95%	-3.41%	-3.13%	-2.59%	-1.74%	-2.51%	-0.163
Partial Equilibrium Consumer Surplus	-4.02%	-3.51%	-3.19%	-2.63%	-1.83%	-2.58%	-0.157
No Demand Response	-4.99%	-4.46%	-3.99%	-3.36%	-2.01%	-3.13%	-0.185

Additional gas tax revenue used to cut labor tax rate:

	Quintile 1	2	3	4	5	Aggregate Tax Burden	Suits Index
Equivalent Variation	-1.17%	-0.87%	-0.88%	-0.55%	-0.47%	-0.65%	-0.175
Partial Equilibrium Consumer Surplus	-1.22%	-0.96%	-0.92%	-0.57%	-0.53%	-0.70%	-0.159
No Demand Response	-2.19%	-1.91%	-1.72%	-1.32%	-0.72%	-1.26%	-0.226

Additional gas tax revenue used to provide lump-sum transfer to households:

	Quintile 1	2	3	4	5	Aggregate Tax Burden	Suits Index
Equivalent Variation	0.45%	-0.53%	-0.93%	-0.92%	-0.85%	-0.75%	0.139
Partial Equilibrium Consumer Surplus	0.42%	-0.60%	-0.96%	-0.94%	-0.92%	-0.80%	0.140
No Demand Response	-0.54%	-1.55%	-1.76%	-1.67%	-1.10%	-1.35%	-0.046

Gas tax is increased to $1.39/gallon in all cases.
Each welfare measure is expressed as a percentage of total expenditures (on gasoline and other goods).

References

1. H. Alderman and D. E. Sahn. Substitution between goods and leisure in a developing country, *Amer. J. Agric. Econom.* **75**, 875-883 (1993).

2. R. Brännlund, and J. Nordström, “Carbon tax simulations using a household demand model,” working paper, Umeå University, 2001.

3. A. Cornwell and J. Creedy, Measuring the welfare effects of tax changes using the LES: An application to a carbon tax, *Empirical Econom*. **22**, 589-613 (1997).

4. C. Dahl, Gasoline demand survey. *Energy J.* **7**, 67-82 (1986).

5. C. Dahl, and T. Sterner, Analyzing gasoline demand elasticities: A survey, *Energy Econom.* **13**, 203-210 (1991).

6. A. Deaton and J. Muellbauer, An almost ideal demand system, *Amer. Econom. Rev.* **70**, 312-326 (1980).

7. M. Espey, Explaining the variation in elasticity estimates of gasoline demand in the United States: A meta-analysis, *Energy J.* **17**, 49-60 (1996).

8. D. Feenberg and E. Coutts, An introduction to the TAXSIM model, *J. Policy Anal. Management* (1993).

9. J. Heckman, Sample selection bias as specification error, *Econometrica* **47**, 153-161 (1979).

10. D. Heien and C. Wessels, Demand system estimation with micro data: A censored regression approach, *J. Business and Econom. Stat.* **8**, 365-1771 (1990).

11. H. Kayser, Gasoline demand and car choice: Estimating gasoline demand using household information. *Energy Econom.* **22**, 331-348 (2000).

12. G. Metcalf, A distributional analysis of green tax reforms, *Nat. Tax J.* **52**, 655-682 (1999).

13. J. Muellbauer, Aggregation, income distribution and consumer demand, *Rev. Econom. Stud.* **62**, 525-543 (1975).

14. J. Muellbauer, John, Community preferences and the representative consumer, *Econometrica* **44**, 979-999 (1976).

15. I. Parry and K. Small, Does Britain or America Have the Right Gasoline Tax?, working paper, Resources for the Future and University of California-Irvine, 2002.

16. J. M. Poterba, Is the gasoline tax regressive? *in* “Tax Policy and the Economy 5” (D. Bradford, Ed.) MIT Press, Boston, 1991.

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

18. J. S. Shonkwiler and S. Yen, Two-step estimation of a censored system of equations, *Amer. J. Agric. Econom.* **81**, 972-982 (1999).

19. K. N. Sipes and R. Mendelsohn, The effectiveness of gasoline taxation to manage air pollution. *Ecol. Econom.* **36**, 299-309 (2001).

20. D. B. Suits, Measurement of tax progressivity. *Amer. Econom. Rev.* **67**, 747-752 (1977).

21. E. Symons, J. Proops and P. Gay, Carbon taxes, consumer demand and carbon dioxide emissions: A simulation analysis for the UK,” *Fiscal Stud.* **15**, 19-43 (1994).

22. M. A.Walls, A. J. Krupnick, and H. C. Hood, “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, 1994.

23. S. West, “Distributional effects of alternative vehicle pollution control policies,” Macalester College Department of Economics Working Paper 2001-01, 2001.

24. S. West and R. C. Williams III, Empirical estimates for environmental policymaking in a second-best setting, work in progress (2002).

25. R. Williams, D. Weiner, and F. Sammartino, “Equivalence Scales, the Income Distribution, and Federal Taxes,” Congressional Budget Office technical paper 1999-2, 1998.

Appendix 1

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.

Appendix 2

Demand Elasticities in Terms of Estimated Parameters

The demand system used in this paper does not yield elasticity estimates directly; instead, the demand elasticities are functions of the estimated parameters. The uncompensated demand elasticity for good *i* with respect to the price of good *j* (where *j* is any good except leisure) is given by

(A1) $$\varepsilon_{ij} = \frac{\gamma_{ij}}{s_i} + \frac{\beta_i \beta_j}{s_i} \log\left(\frac{y}{P}\right) - d_{ij} + \frac{\beta_i s_j}{s_i}$$

where s_i is expenditure on good *i* as a share of full income, and where d_{ij} is the Kronecker delta, equal to 1 if *i*=*j* and zero otherwise.

The uncompensated demand elasticity for good *i* with respect to a change in the wage (either the male wage or the female wage in the case of a two-earner household) is given by

(A2) $$\varepsilon_{ij} = \frac{\gamma_{ij}}{s_i} + \frac{\beta_i \beta_j}{s_i} \log\left(\frac{y}{P}\right) - d_{ij} + \frac{\beta_i}{s_i}\left(s_{Lj} - s_j\right) + s_{Lj}$$

where s_{Lj} is the share of the particular individual's time endowment in total income for the couple: that individual's wage times his/her time endowment divided by *y*. Thus, for example, if both individuals in a couple have the same wage (and the same time endowment), and non-labor income is zero, then $s_{Lf} = 0.5$ and $s_{Lm} = 0.5$. Similarly, for a single-earner household with zero non-labor income, s_L is 1.

The compensated elasticity of demand for good *i* with respect to the price of good *j* is given by

(A3) $$\varepsilon_{ij}^{C} = \frac{\gamma_{ij}}{s_i} + \frac{\beta_i \beta_j}{s_i} \log\left(\frac{y}{P}\right) - d_{ij} + s_j$$

Finally, the income elasticity of demand for good *i* is given by

(A4) $$\varepsilon_i^I = \frac{\beta_i}{s_i} + 1$$

Equation (A1) is derived by taking the derivative of the demand function implied by the Deaton-Muellbauer system (see equation 8 in Deaton and Muellbauer, [6]) with respect to price, converting the derivative into an elasticity, and simplifying. A similar process with respect to income yields (A4). Deriving the uncompensated elasticity with respect to the wage (A2) is similar to the derivation of (A1), but one must account for the change in full income that results from a change in the wage. The process for deriving the compensated elasticity (A3) is also similar, but uses the Slutsky equation, because the demand function given in Deaton and Muellbauer [6] is uncompensated.

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[2] See also Dahl [4], Dahl and Sterner [5], and Espey [7] for reviews of the gasoline demand literature.

[3] Metcalf [12] also considers different scenarios for the use of environmental tax revenue, holding household behavior constant, and finds that a reform can be designed so that replacement of other taxes by environmental taxes can have a “negligible effect on the income distribution” (p. 655).

[4] West [23] allows for behavioral responses when calculating distributional effects, but does not include cross-price effects. Cornwell and Creedy [3] use a linear expenditure system (LES) to determine the distributional effects of a carbon tax in Australia. The LES allows them to consider many markets simultaneously, but imposes separability among goods. They also hold labor supply constant. Symons et al. [21] use the more flexible almost ideal demand system to determine the effects of a carbon tax in Sweden. Their system does not include labor supply.

[5] 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.

[6] Alderman and Sahn [1] and Heien and Wessels [10] 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. Shonkwiler and Yen [18] find that especially in the case of a large number of censored observations, the Heien and Wessels [10] procedure is biased. Two factors suggest that this bias is unlikely to significantly influence our results. First, we have only a small number of censored observations: in the one-adult sample, 481 households buy no gasoline; in the two-adult sample 135 households buy none. Second, use of estimates from regressions that make *no* correction for sample selection do not significantly affect incidence results.

[7] This equivalence scale is suggested by Williams *et al.* [25], 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.

[8] Appendix 2 provides equations for these elasticities in terms of the estimated parameters.

[9] These are short-run elasticities; households in our system do not respond to gas price increases by, for example, buying more fuel-efficient cars. To the extent that wealthier households may be more able than poor households to avoid gas taxes in the long run by switching vehicles, our use

of short-run elasticities will result in incidence estimates that are biased towards greater progressivity.

[10] Because the initial level of the gas tax differs across states, the average gas tax rate paid differs slightly across quintiles. Thus, because the gas tax is increased to the same level for all quintiles, the amount of the tax increase also varies slightly across quintiles. The results would be very similar, however, if we were to hold the tax increase, rather than the new tax rate, constant across quintiles; the difference between the highest tax rate faced by any quintile and the lowest is less than three cents.

[11] The effects of an increase in gas prices on other goods is likely to be small: Metcalf [12] uses Benchmark Input-Output Accounts to determine the effect of a 15% gas price increase on other goods' prices. He finds that other goods' prices increase by no more than 0.6%; most goods' prices increase by 0.2% or less. Our scenario increases gas prices by about 85%, implying that other goods' prices would rise by no more than 3.4%.

[12] Consumer surplus for each good is the integral over the quantity purchased of the difference between the inverse demand and the price. We assume a constant-elasticity demand curve, calculate the change in this integral resulting from the change in price, sum over all goods, and simplify yield equation (12).

[13] The equivalent variation is the change in income that–holding prices constant–would yield the same change in utility as do the new prices and transfers. Equation (13) is derived by calculating the change in expenditure to yield the same utility change, using the Deaton-Muellbauer expenditure function (equation 4 from Deaton and Muellbauer [6]) and the indirect utility

function, then subtracting the change in the transfer. Simplifying the resulting expression yields equation (13). The indirect utility function (equation 14) is derived by inverting equation (4) from Deaton and Muellbauer [6] and simplifying.

[14] Equation (15) is equivalent to equation (4) from Suits [20], except that it bases the calculation on five quintiles, rather than on ten deciles.

[15] This may seem inconsistent with Suits [20] finding that the payroll tax is regressive. The difference results because we consider a cut in the tax rate for all brackets, which is roughly a proportional tax change, whereas the Social Security payroll tax has a cap, making it regressive.