Per Mile Emissions Taxes And Lump Sum Emissions Taxes: A Comparative Study Using A Mathematical Approach To Demand Estimation

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ABSTRACT

The primary purpose of this study was to utilize the mathematical approach to demand estimation developed in Culp (2004) to compare two common emissions based taxes. The model assumes Cournot-Nash behavior and divides the automobile market into five homogenous segments. A global optimization program is utilized to mathematically determine the range of values the coefficients of demand must take in each segment to satisfy market equilibrium. Simulations were performed to examine the comparative impact on social welfare of both the per mile emission tax (PMET) and the lump sum emission tax (LSET) in the automotive and travel markets. In the simulations, a global optimization program allows market conditions to change while holding constant the level of pollution reduction, satisfying the other constraints of the model, and satisfying each firm's first order profit-maximizing conditions.

The simulation found that in five of the thirty-two quarters examined, and regardless of market conditions, that the LSET produced more gains from trade. In simulations of the remaining quarters, the outcomes varied depending upon the cross price elasticity of vehicle demand and upon the sensitivity of consumers to vehicle operating cost.

The simulations also show that an approximately 20 percent reduction in emissions from new vehicles is achieved by the LSET with a median tax rate of $155.74 per gram of average CO emissions per mile. Consequently, a vehicle that emits an average of two grams of CO per mile would pay a one-time fee of $311.48. The median tax rate required by the PMET is $0.00666 per gram per mile. Accordingly, a vehicle that emits two grams of CO per mile on average would pay $0.0103 per mile or $1332.46 for every 100,000 miles traveled. The difference between the two tax rates, required to achieve the same pollution reduction goal, is likely the result of consumer's insensitivity to the rise in vehicle operating costs caused by the PMET. This result is consistent with the view that consumers highly discount future payments.

THE SIMULATION OF THE EFFECT OF PMET AND LSET

In this paper, an abatement cost function will be specified and used to determine how the LSET and PMET changes each firm's first-order conditions and how these new first-order conditions change market outcomes.

A per mile emissions tax (PMET) is an emissions tax which is paid each year by the consumer based upon the vehicle's total estimated emissions over the period. Such a tax is based upon the number of miles driven and the emissions per mile of the vehicle. Vehicles with higher emissions would pay a higher tax for the same number of miles driven. Proponents argue such a tax could be collected each year at vehicle registration upon inspection of number of miles driven during the year. The PMET tax seeks to reduce pollution in two ways: by raising the cost of travel, particularly for those with higher emission vehicles, and second by increasing automakers production of lower emission vehicles in response to consumers' increased demand for lower emission caused by the per mile emissions tax.

A lump sum emissions tax (LSET) seeks to reduce emissions from vehicles by encouraging producers to produce lower emission vehicles by making the automaker pay a one-time tax based upon the emissions characteristics of the vehicle. Higher emission vehicles produced by the automakers would pay a higher tax than lower emission vehicles. Since the LSET is not paid per mile driven, the LSET does not change the cost of travel and therefore has no effect on vehicle miles traveled.

To estimate the effect of the PMET on automobile demand, gasoline prices are used as a proxy for the PMET. The PMET increases the cost of vehicle travel and consumers should respond to an increase in operating costs caused by the PMET the same way they respond to an increase in operating costs caused by changes in gasoline prices.

To estimate the effect of the LSET on automobile demand is less complex since consumers should react to increases in the LSET the same as they would react to increases in vehicle prices. Therefore, estimating the effect of the LSET on demand should be equivalent to estimating the effect of a per unit tax.

The next step is to simulate how the changes in demand resulting from taxation will affect firm behavior and thus equilibrium output, pricing, and producer and consumer surplus. For the PMET, a firm will decide to implement new pollution abatement technology to counter the tax-driven changes in demand if two conditions are met: 1) the addition of pollution abatement technology can be linked in the minds of consumers as making a vehicle cheaper to operate and therefore more desirable. 2) The firm expects its profits to increase enough from the increase in demand caused by implementing the new abatement technology to pay for the costs of lowered emissions. The first condition is met, as stated earlier, because consumers are assumed to react to each tax as they have reacted to changes in gasoline prices. The second condition depends on the increase in production costs resulting from producing lower emission vehicles. The increase in production costs will be given by a reasonable function that fits the assumption of increasing implementation costs per additional unit of pollution reduction.

It is assumed each automaker will produce all vehicles within a segment using the same chosen technology rather than applying different designs. In addition the technology chosen will only require simple changes that add cost to each vehicle but need little equipment or capital expenditures to implement. It is also assumed that all firms have access to this abatement technology and therefore each automaker will choose the same level of pollution reduction for each segment. The firm is assumed to benefit only from the improved price and sales of its vehicles due to the reduction in tax. Although there may be other "good-will" benefits, these benefits will be ignored.

DATA

The data for this analysis is taken from Culp (2004) and refers to the 32 quarters of pricing and output observations of the automobile market from 1989-1996. Vehicle prices were obtained from the Consumer Expenditure Survey and vehicle sales information was obtained from Ward's Automotive.

BASIS OF THE ABATEMENT COST FUNCTION

To ensure that the abatement cost function does not exceed the cost of existing technology, propane and natural gas powered vehicles were chosen as representative methods of emission reductions and the abatement function adapted to fit closely the cost of adopting these available technologies. Since any form of abatement with a greater cost than propane or natural gas for the same level of abatement would not be chosen by firms, these technologies represent the high end of abatement costs. Therefore, the abatement function for each segment will be adjusted not to exceed the cost of this technology. Propane and natural gas were chosen not only because the cost of adopting this technology is well-known but also because they achieve significant pollution reduction without significantly changing vehicle characteristics, new vehicles can be easily converted to their use, and because much of the infrastructure needed to supply this alternative fuel to consumers already exists. Therefore, propane and natural gas are good indicators of the maximum amount firms will be willing to spend for similar levels of pollution reduction.

PRODUCTION COSTS OF LOWER EMISSION VEHICLES BY SEGMENT

This paper focuses on carbon monoxide emissions (CO) since the health impacts of CO emissions are well known and these emissions are greater than any other ground level pollutant. Additionally, other pollutants such as nitrogen oxides (NOx) and volatile organic compounds (VOCs) that cause ozone tend to be reduced when CO is reduced.

Vehicles are grouped into three emissions categories as determined by the EPA: Ultra low emission vehicles, standard car emissions under Tier 1, and standard truck emissions under Tier 1. Tier 1 was the required emissions for vehicles by 1994.

Ultra low emission vehicles tend to be in the small car segment and emit 2.1 grams of CO per mile or less. Standard cars under Tier 1 include all vehicles except pickups and SUVs. They are required to emit less than 4.2 grams of CO per mile. Truck emissions include pickups and SUVs and are required to emit less than 5.5 grams of CO per mile.

The reason for the splitting vehicles into three emissions categories is that vehicles of different size and performance are going to require different levels of pollution abatement and consequently be more expensive. Table 1 was constructed from information provided by the Natural Gas Vehicle Coalition. It indicates the additional cost per vehicle for producing propane and compressed natural gas (CNG) vehicles in place of gasoline engines and the resulting emissions.

The cost of compressed natural gas vehicles is more than propane because natural gas must be stored at a higher pressure requiring much sturdier storage tanks. The cost of implementing propane and compressed natural gas varies depending on how large the storage capacity must be to deliver similar driving ranges. For smaller vehicles, the lower end of each estimate would be most appropriate, while for larger vehicles the higher end of each estimate would most accurately reflect the cost to implement.

Table 1: Cost of Emissions Reduction from Selected Alternate Fuels

Fuel	Additional production cost per vehicle	Pollution reduction	CO Emissions compared to gasoline engine with 2.1 grams of CO per mile	CO Emissions compared to gasoline engine with 4.2 grams of CO per mile	CO Emissions compared to gasoline engine with 5.5 grams of CO per mile
Propane	\$1000-\$2000	60%	0.84	1.68	2.20
CNG	\$4000-\$6000	90%	0.21	0.42	0.55

For example, Table 1 shows that if a gasoline engine that currently emits 2.1 grams of CO per mile is converted to propane, the vehicle will cost an additional \$1000-2000, but emissions will be reduced from 2.1 to only 0.84 grams of CO per mile. When the same vehicle is converted to CNG, the vehicle will cost an additional \$4000-\$6000, but emissions will be reduced from 2.1 to only 0.21 grams of CO per mile.

An abatement cost function was selected to be consistent with the mathematical criteria of diminishing returns and increasing cost. In particular, the abatement function was specified to take the following mathematical form:

$$\text{Emissions per mile} = \frac{\$x \text{ CO grams per mile}}{\text{additional vehicle cost}} \qquad (1)$$

where the x is adjusted based upon the size of the vehicle. Vehicles in each segment were placed in the emissions category that most closely represents their emissions level as of 1989: X is $840 for small vehicles, $2200 for pickups, $2200 for SUVs, $1680 for luxury vehicles, and $1680 for large cars.

The abatement constant is simply adjusted to represent the different levels of emissions produced by vehicles with different sizes and characteristics for the same additional cost. For example, for the same additional amount spent on abatement equipment, larger vehicles will probably produce more emissions per mile than small vehicles. Therefore, the abatement constant is adjusted depending on the emissions characteristics of the current vehicle with a larger constant representing the increased difficulty of emissions reduction.

The abatement function exhibits diminishing returns and it yields results for each category of vehicles that are comparable to the pollution reduction actually achieved by propane and natural gas when the abatement constant is adjusted according to the vehicle category. For example, a vehicle that currently emits 2.1 grams of CO per mile using gasoline can have its emissions reduced to 0.84 grams of CO per mile for $1000-$2000 per vehicle using propane, or reduced to 0.21 for between $4000-6000 using compressed natural gas. The estimated abatement function should be consistent with this information, and the abatement constant in each segment was chosen so that this would be accomplished. When the abatement constant in the abatement function show in equation 1 is set to a value of $840, spending $1000 on abatement equipment causes emissions to be 0.84. This matches the $1000-2000 known cost of converting a small size vehicle to propane. Likewise, to reduce emissions to 0.21, the amount of abatement spending is $4000. Again, this matches the cost of emissions reduction achieved when CNG technology is used. As Table 1 shows, CNG costs $4000-$6000 and emissions are reduced for small vehicles from 2.1 grams of CO per mile to 0.21.

This equation shows, for example, that to reduce emissions to 0.84 it only requires $1000 per ultra low emission vehicle that currently emits 2.1 grams of emissions. However, for the larger Tier 1 vehicles, that emit 4.2 grams of emissions, it would require $2000 per vehicle, and for trucks that emit 5.5 grams of CO per mile, it would require more than $2500 per vehicle to come close to the 0.84 grams of emissions achieved for only $1000 with ultra low emission vehicles.

Now that the abatement cost functions have been specified, we have the information necessary to determine the level of emissions that will maximize profits for each firm. Since firms make decisions on the margin, in order to maximize profits each firm will seek to reduce emissions as long as the marginal benefit is greater than or equal to the marginal cost of emissions reduction. Therefore, the marginal cost and marginal benefit to each firm under each tax needs to be calculated.

OPTIMAL EMISSIONS FOR FIRMS UNDER THE PMET

The total cost function is needed to calculate the marginal cost of pollution reduction under the PMET. The first step to derive the total cost function is solving the abatement function in terms of additional cost per vehicle.

Since the abatement function is: $$\text{emissions} = \frac{1}{\text{additional cost}} \cdot \text{abatement constant} \qquad (2)$$

Total cost can be found by multiplying additional cost per vehicle by quantity.

$$\text{total cost of emissions reduction} = \frac{\text{abatement constant}}{\text{emissions}} \cdot \text{quantity} \qquad (3)$$

To find the marginal cost of emissions reduction for the PMET, the derivative of equation (3) with respect to emissions will be performed. These yields:

$$\text{Marginal cost of emissions reduction} = -\frac{\text{abatement constant}}{\text{emissions}^2} \cdot \text{quantity} \tag{4}$$

Now that the marginal cost of emissions is known for the PMET, the marginal benefit of emissions reduction to the firm needs to be calculated. The benefit to the firm of reducing pollution under the PMET is simply the higher market price and greater number of units the firm can sell.

The change in demand that results from the higher PMET is calculated as $\frac{\partial P}{\partial Gas} \cdot PMET$ where $\frac{\partial P}{\partial Gas}$ (DGAS) is a proxy for the effect of the PMET on the price of vehicles.

Therefore, the marginal benefit to the firm of emissions reduction is:

DGAS * PMET* quantity of vehicles (5)

Set marginal cost equal to marginal benefit to find the optimal level of emissions:

$$-\frac{abatement\ constant}{emissions^2} \cdot quantity = \frac{\partial P}{\partial Gas} \cdot PMET \cdot quantity \tag{6}$$

Solving for emissions yields:

$$emissions^* = \left(\frac{abatement\ constant}{\frac{\partial P}{\partial Gas} \cdot PMET} \right)^{\frac{1}{2}} \tag{7}$$

The asterisk designates that this is the optimal amount of emissions under the PMET. Substituting the optimal emissions level into the abatement equation generates the additional cost per unit of achieving the optimal level of pollution reduction.

MARKET EQUILIBRIUM CONDITIONS AND FIRST ORDER CONDITIONS

Culp (2004), showed demand could be estimated in the automobile market by simply observing firm output and pricing decisions and by making certain assumptions about the structure of the automobile market. The four key assumptions of the Culp model are: 1) the automobile market consists of five homogeneous segments consisting of SUVs, pickups, luxury vehicles, large vehicles, and small vehicles. 2) The automobile market consists of five firms behaving in the Cournot-Nash framework. 3) The marginal cost of the last vehicle produced by each firm is not known but can be assumed to exist between certain ranges. 4) Firm production in one segment does not change the cost of producing a vehicle in another segment. Culp used this information to estimate own price elasticities for each vehicle segment. The first-order conditions derived in Culp (2004) based upon these assumptions are:

$$p_n^i + \frac{\partial p_1}{\partial q_n} \cdot \mathrm{q}_1^{\mathrm{i}} + \frac{\partial p_2}{\partial q_n} \cdot \mathrm{q}_2^{\mathrm{i}} + \frac{\partial \mathrm{p}_3}{\partial \mathrm{q}_\mathrm{n}} \cdot q_3^i + \frac{\partial \mathrm{p}_4}{\partial \mathrm{q}_\mathrm{n}} \cdot \mathrm{q}_4^{\mathrm{i}} + \frac{\partial \mathrm{p}_5}{\partial \mathrm{q}_\mathrm{n}} \cdot \mathrm{q}_5^{\mathrm{i}} - \mathrm{MC}_\mathrm{n}^\mathrm{i} = 0 \tag{8}$$

where p is the observed price in each segment, i is the firm for n=1 to 5, the subscript numbers indicate the vehicle segments, and n designates the segment for which the FOC is being applied.

Using the optimal level of emissions found above creates the following new first order conditions for the PMET:

FOC under PMET

$$p_n^i + \frac{\partial p_1}{\partial q_n} \cdot q_1^i + \frac{\partial p_2}{\partial q_n} \cdot q_2^i + \frac{\partial p_3}{\partial q_n} \cdot q_3^i + \frac{\partial p_4}{\partial q_n} \cdot q_4^i + \frac{\partial p_5}{\partial q_n} \cdot q_5^i - MC_n^i - tax_n^i = 0 \tag{9}$$

For each ith firm, where the first term is the new price consumers are willing to pay for vehicles given the higher travel costs, and where n is the segment for the type of vehicle being produced. How the change in vehicle operating costs affect the prices consumers are willing to pay for vehicles is shown by the inverse demand curves, discussed in the next section. The tax variables represent the additional production cost to each firm at the optimal level of emissions resulting from the abatement technology chosen, and MC is the marginal costs for each firm in each segment. The next section will examine how the PMET changes demand.

CHANGE IN DEMAND CAUSED BY THE PMET

The new price consumers are willing to pay is the original demand equation less the change in demand caused by PMET. The change in demand for vehicles caused by the PMET is represented by how consumers have reacted to changes in vehicle operating costs in the past, in particular, to gasoline prices. The change in demand in each segment is represented by the DGAS variables. These variables show the change in vehicle price in each segment caused by the change in per mile operating costs.

Change in per mile operating costs under the PMET is the amount of the tax per unit of emissions times the emissions per mile, represented by the epm variables in the following equations. Therefore, the linearized demand equations developed in Culp are changed by subtracting DGAS * PMET*EPM from each inverse demand equation. This equation shows the change in vehicle prices caused by the PMET. The following are the adjusted inverse demands for each ith firm in each market segment under the PMET.

$$P_n^T = \mathrm{Constant}_n + \frac{\partial p_n}{\partial q_1} \cdot Q_1^T + \frac{\partial p_n}{\partial q_2} \cdot Q_2^T + \frac{\partial p_n}{\partial q_3} \cdot Q_3^T + \frac{\partial p_n}{\partial q_4} \cdot Q_4^T + \frac{\partial p_n}{\partial q_5} \cdot Q_5^T - \frac{\partial p_n}{\partial gas} \cdot \mathrm{PMET} \cdot \mathrm{epm}_n \tag{10}$$

Where P^T is the price after PMET and in segment n and Q^T is the quantity in each segment after tax.

OPTIMAL EMISSIONS FOR FIRMS UNDER THE LSET

Since it is assumed that the incidence of per unit taxes does not change outcomes, the LSET will be placed on each firm rather than on consumers. Each firm benefits from lower emissions because it pays a lower tax on each vehicle it produces. Firms will then select the level of emission reduction that maximizes profits.

The objective for each firm under the LSET is to maximize the following profit equation:

$$\mathrm{Max\,profit} = P \cdot Q - TC_{manufacturing} - TC_{abatement} - \mathrm{Total\,taxes} \tag{11}$$

where P is the vector of prices, Q is the vector of quantities, is the total cost of manufacturing, is the total cost of abatement and total taxes is the total of LSET taxes paid by the firm.

$TC_{abatement}$ $TC_{manufacturing}$

Since it is assumed access to technology is the same under the LSET as under the PMET, the total cost of abatement function is:

$$\mathrm{TC}_{\text{abatement}} = \frac{\text{abatement constant}}{\text{emissions}} \cdot \mathrm{Q} \tag{12}$$

and the total amount of taxes each firm will pay is:

$$\textit{Total taxes} = \textit{emissions} \cdot \textit{LSET} \cdot \textit{Q} \tag{13}$$

where emissions is the vector of emissions in each segment, and LSET is the tax rate for each unit of emissions.

Each firm will seek to maximize profits by changing the variables under its control. Each firm controls the quantity produced and the emissions of their vehicles. The optimal emissions for each firm can be found by taking the derivative with respect to emissions.

Taking the derivative of the profit equation with respect to emissions yields:

$$\frac{\partial \text{Profits}}{\partial \text{emissions}} = \frac{\partial \mathrm{TC}_{\text{abatement}}}{\partial \text{emissions}} = \frac{\text{abatement constant}}{\text{emissions}^2} \cdot \mathrm{Q} - \mathrm{LSET} \cdot \mathrm{Q} \tag{14}$$

$$\frac{\text{abatement constant}}{\text{emissions}^2} \cdot \mathrm{Q} - \mathrm{LSET} \cdot \mathrm{Q} = 0 \tag{15}$$

$$\mathrm{LSET} \cdot \mathrm{Q} = \frac{\text{abatement constant}}{\text{emissions}^2} \cdot \mathrm{Q} \tag{16}$$

Setting FOC equal to zero and solving for emissions:

$$\text{emissions}^* = \left(\frac{\text{abatement constant}}{\mathrm{LSET}} \right)^{\frac{1}{2}} \tag{17}$$

This is the optimal emissions for each firm under the LSET. Substituting the optimal emissions into the abatement function yields the additional per vehicle cost of these optimal emissions. Since it is known in environmental economic theory that a firm will continue to add abatement equipment until the marginal cost of the abatement equipment equals the tax, the change in per vehicle cost is equal to the per vehicle tax under the LSET.

Therefore, each firm's production cost will increase by the amount of the tax and each firm will have to pay an equal amount in taxes for each unit produced. Therefore, the marginal cost of both the tax and the increased production costs are twice the amount of the tax.

The FOC for the LSET are the same as the original FOC for the LSET except the cost of the firm to produce has changed by both the amount of the tax and the increased production costs.

At optimal level of abatement, this is simply two times the amount of the tax.

FOC under LSET

$$P_n^i + \frac{\partial p_1}{\partial q_n} \cdot q_1^i + \frac{\partial p_2}{\partial q_n} \cdot q_2^i + \frac{\partial p_3}{\partial q_3} \cdot q_3^i + \frac{\partial p_4}{\partial q_4} \cdot q_4^i + \frac{\partial p_5}{\partial q_5} \cdot q_5^i - MC_n^i - 2 \cdot tax_n^i = 0 \tag{18}$$

For each ith firm for each vehicle segment n=1 to 5. The tax variables show the additional cost of production and the per vehicle tax producers pay. The inverse demand curves are the same as the ones found in earlier in this paper since vehicle characteristics are unchanged by the LSET.

Therefore, the only change to price that will occur will be caused by changes in the market equilibrium as the result of the increased marginal costs paid by each firm and the resulting decrease in output. The following are the inverse demand equations under the LSET. Where n is the segment in which the car is being produced and Q^T is the total market output in each of the five segments.

$$P_n^T = \text{Constant}_n + \frac{\partial p_n}{\partial q_1} \cdot Q_1^T + \frac{\partial p_n}{\partial q_2} \cdot Q_2^T + \frac{\partial p_n}{\partial q_3} \cdot Q_3^T + \frac{\partial p_n}{\partial q_4} \cdot Q_4^T + \frac{\partial p_n}{\partial q_5} \cdot Q_5^T \tag{19}$$

Social Welfare Optimization Comparisons under Each Tax

Having developed the new FOC for the PMET and LSET, the impact of these taxes can now be analyzed. These first order conditions should result in different prices, levels of production, and levels of abatement technology implemented given different levels of taxation under the PMET and the LSET. From these market results, net emissions reduction under each tax will be determined, relevant consumer and producer surpluses calculated, and comparisons made between the two tax schemes.

CRITERIA FOR EVALUATING RESULTS

To evaluate each tax, an optimization program adjusts each tax rate until the PMET and the LSET reduce pollution by the same amount. Pollution reduction is set equal to avoid having to adjust for any extra pollution reduction. Since the value of pollution reduction is often debated, this would add another complication and another possible source of error to the model.

While pollution reduction under each tax is the same, the amount of consumer surplus and producer surplus in each market under each tax will differ. The tax that creates more gains from trade in the automotive and travel markets while achieving the same amount of pollution reduction will be judged superior.

Given that the other market conditions are the same for each tax, the optimization program will determine the largest possible difference in the total gains from trade achieved under one tax compared to the other. In doing this, the optimization program will adjust the tax rates, the coefficients of demand, and any other unknown variable. The program will also adjust each firm’s output so that first order conditions are satisfied for market equilibrium.

The objective is to find if one tax is always superior to the other regardless of how market conditions change within their bounds. This would occur if the largest possible difference were always in favor of one tax.

CALCULATION OF NET POLLUTION REDUCTION

Both the PMET and LSET are levied on new cars. This is done so that each tax is placed on potentially the same number of consumers, and it is likely the government would phase in either tax so that fewer consumers would bear the burden of the tax, and thus, lessen political opposition.

As stated earlier, both reducing vehicle miles traveled and lowering emissions per mile achieve pollution reduction; however, if in response to these taxes some consumers decide to hold on to older, more polluting vehicles, the gains achieved by lower emissions on new vehicles will be offset by the increased presence of older vehicles remaining in service.

Therefore, pollution reduction is calculated as:

$$\begin{aligned}&\text{Net emissions reduction} = \\ &\text{Amount of emissions from new vehicles with no tax} - \\ &\text{Amount of emissions from new vehicles with tax} - \\ &\text{Additional emissions caused by consumers who hold on to older vehicles}\end{aligned} \tag{20}$$

$$\begin{aligned}&\text{Additional emissions caused by consumers holding onto older vehicles} = \\ &\text{Decrease in auto sales} \bullet \text{emissions caused by the oldest, non - gross polluter vehicles}\end{aligned} \tag{21}$$

In estimating the additional emissions caused by consumers holding on to older vehicles, all lost vehicle sales are assumed to result in an old, non-gross polluting vehicle remaining in operation. Even though, it is assumed that each lost new vehicle sale causes an old vehicle to remain in operation, it is assumed that this old vehicle is not a gross polluter because of state and local inspection programs designed to eliminate such gross polluters. Instead, the pollution emitted from vehicles that would have been scrapped will be assumed equal to the average in-use emissions for vehicles. In-use emissions are obtained from remote sensing equipment of vehicles in use. The measurements taken vary greatly but the greatest preponderance of observations is between 5 and 10 grams of CO per mile (Wenzel, 1999). Therefore, in this paper it will be assumed that vehicles that stay on the road emit 7.5 grams of CO per mile.

EMISSION REDUCTION MECHANISMS UNDER THE PER MILE EMISSION TAX

The first tax to be examined is the PMET. The PMET achieves pollution reduction by both encouraging producers to produce lower emission vehicles and by reducing vehicle miles traveled. To calculate the effectiveness of the PMET, a travel demand function needs to be estimated so the PMET's impact on vehicle miles traveled and social welfare in the travel market can be determined. Next, the relationship between operating costs and vehicle sales will be explored so the PMET's impact on new vehicle demand can be estimated.

Estimation of Travel Demand with Respect to Operating Costs

The demand for travel depends on many different factors, but of interest to this paper is how the price per mile traveled changes the quantity of vehicle miles traveled. A linear form of travel demand will be assumed of the following form:

$$\text{Quantity of travel demanded} = \text{intercept} + \text{slope} \cdot \text{price} \tag{22}$$

The slope of travel demand has been the focus of other researchers and their results will be used in this paper. The slope measures how vehicle miles traveled changes with each change in price. If the slope, price, and quantity of travel are known, then the intercept can be calculated and a demand function can be estimated. In this paper, it is assumed that the price of travel is 25 cents per mile and that each vehicle owner travels 12,000 miles each year on average. The price of travel figure is approximately based on the reimbursement rate paid by the U.S. government (Federal Register, 1999) to its employees reflecting the additional cost of each mile traveled.

The price of travel figure is used for vehicles of all sizes because the difference in the cost between small sedans and SUVs for maintenance, tire wear, and gasoline and oil used is only 3.2 cents (AAA, 2000). However, as a more practical matter, the elasticities for travel used in this paper from other studies are not broken down by vehicle segment. In addition, the vehicle miles traveled figures are also averaged for all vehicle types. Therefore, using different vehicle operating costs depending on vehicle segment would be problematic because it is unknown from the aggregated studies whether the elasticity of travel demand and vehicle miles traveled is the same for all vehicle segments. Consequently, the value of travel will be estimated using average vehicle miles traveled and average per mile cost, and these will be assumed uniform for each segment.

The average annual vehicle miles traveled per year is based on information collected by the Residential Transportation Energy Consumption Survey published by the Department of Energy (DOE). The DOE survey estimated vehicle miles traveled at 11,400 miles per vehicle in 1994 and vehicle miles driven in the first year in 1994 at 14,300 miles. Auto and tire manufacturers for warranty coverage purposes use a 12,000 mile per year figure. This figure is used not only by these companies, but also by the EPA report when it reports expected vehicle emissions. Because the 12,000 miles per year figure is in common use and close to the 1994 energy consumption figures, it is used for this paper.

Now that price and quantity of travel are defined, the only remaining figure needed to calculate the intercept of travel demand is the slope of travel demand. Heninger and Shah (1998) calculate an elasticity of vehicle miles traveled (VMT) with respect to gasoline prices per mile of –0.192. This means that a 1 percent increase in travel cost causes a 0.192 percent decrease in miles traveled. If the price of travel is $0.25 per mile, then a 4 percent increase in travel causes a one-cent increase in travel cost and a 0.768 percent drop in VMT. This would cause vehicle miles traveled for the average 12,000 miles per year consumer to drop by 92.16 miles. This figure is the slope of travel demand in cents.

Solving the demand equation for the intercept and substituting generates the demand equation:

Therefore, travel demand is:

$$12000 \text{ miles} = \text{intercept} - 92.16 \text{ miles/cent} \cdot 25 \text{ cents}$$

$$\textit{Travel demand} = 14{,}304 \text{ miles} - \mathit{92.16} \text{ miles/cent} \cdot \textit{price of travel} \text{ in cents} \tag{23}$$

$$\textit{intercept} = 14304 \text{ miles}$$

Now that travel demand has been determined, how the PMET changes travel demand will be estimated.

Travel Demand under the PMET

Since the PMET increases the price of travel, it will reduce the number of miles traveled. The size of the reduction also depends on the elasticity of supply. For this paper, it was assumed that supply in the travel market is perfectly elastic. This assumption is not unreasonable because commodity markets tend to have very elastic long run elasticities.

With a perfectly elastic supply, any increase in travel cost is borne entirely by the consumer. This means that the PMET changes demand in the following manner:

$$\begin{gathered}\textit{Travel demand} = \\ \mathit{14{,}304} \text{ miles} - \mathit{92.16} \text{ miles/cent} \cdot (\textit{Price of travel} + \textit{PMET} \cdot \textit{Emissions per mile}) \text{ in cents}\end{gathered} \tag{24}$$

Now that the impact of the PMET on travel demand has been found, the next step is to establish how much increases in vehicle operating costs reduce vehicle sales so that the change in new vehicle sales under the PMET can be determined.

Impact of Operating Costs on New Vehicle Demand

Since the PMET increases the cost of travel, an increase in its cost should change vehicle demand in the same way other increases in operating cost have changed demand for vehicles. Several studies have been performed on vehicle operating cost and sales. Most commonly, gasoline prices have been studied. Pritchard and DeBoer (1995) found vehicle sales elasticities with respect to gasoline prices between –0.096 and –0.107 depending on model in their 1986 study. Berndt, Friedlaender, and Shaw-Er Wang Chaing (1990) found elasticity to be between –0.80 and –7.97 for 1983 and in their multi-year study, their work showed an inelastic trend since1959. Finally Arguea, Hsiao, and Taylor (1994) found elasticity to be between –0.211 and –0.208 with respect to vehicle sales and miles per gallon characteristics, depending on the statistical method used.

Since the Pritchard and DeBoer estimates for operating cost elasticity lie between the other studies' estimates, their estimate of 0.107 for elasticity of operating cost to vehicle demand will be used to determine how vehicle prices change when vehicle operating costs increase on a per mile basis.

First the gasoline elasticity must be converted to the impact of a per mile increase in cost on vehicle price, henceforth referred as DGAS.

With elasticity of vehicle sales to gasoline prices =

$$\frac{\%\text{ change in quantity of vehicles sold}}{\%\text{ change in gasoline prices}} \tag{25}$$

Given gasoline prices were around $1 per gallon in 1989; this implies a one-cent increase is equivalent to a one percent increase in gasoline prices. In addition, with weighted fuel economy at about 26 miles per gallon in 1989, a one percent increase in gasoline prices would cause per mile vehicle operating cost to increase by 1/26 of a cent. Therefore, a 1/26 of a cent increase in per mile vehicle operating cost would result in a 0.107 percent drop in vehicle sales, based upon the elasticity of gasoline demand found by Pritchard and DeBoer. Consequently, a one cent increase in per mile operating costs ,which is to say a 26 cent/gal price increase, would cause vehicles sales to drop by 2.782 percent. This is an elasticity of vehicle sales to per mile operating cost of 2.782.

The percentage drop in vehicle sales due to per mile operating costs figure multiplied by the total sales in each segment represents the total sales lost per one-cent increase in per mile operating cost. However, since the demand equations in this paper are in inverse form, this figure must be divided by the inverse of the slope of inverse demand to determine the impact on vehicle prices. The result is the change in vehicle prices caused by a change in per mile operating costs, Dgas.

Ideally, the value of DGAS would be calculated at each point with the current estimated slope of the demand curve; unfortunately, allowing these variables to vary exceeds the capacity of the global optimization program. However, Culp calculated the maximum and minimum coefficients of demand in each segment for each quarter. These maximum and minimum coefficients of demand will be used as constraints and the value of DGAS in the optimization program will be allowed to change within these bounds.

Now that the influence of vehicle operating costs on sales has been specified, the pollution reduction achieved under the PMET can be estimated.

POLLUTION REDUCTION CALCULATIONS UNDER PMET

Pollution reduction is calculated as the difference between total emissions before the PMET less total emissions after the PMET has been implemented. Since it is assumed the PMET is on new vehicle sales, how the tax changes the behavior of those consumers who were planning on a new vehicle purchase is the relevant group. How pollution changes for this group will be calculated as follows:

$$\begin{aligned}&\text{Total emissions without PMET} =\\&\text{Existing emissions per mile before the PMET} \cdot \text{number of miles traveled}\\&\cdot \text{number of vehicles sold before PMET}\end{aligned} \tag{26}$$

$$\begin{aligned}&\text{Total emissions after PMET} =\\&\text{emissions from new vehicles}\\&+ \text{emissions from vehicles that would not be in use but for the PMET}\end{aligned} \tag{27}$$

$$\begin{aligned}&\text{Emissions from new vehicles} =\\&\text{number of miles traveled by new vehicles after PMET}\\&\cdot \text{new vehicle emissions} \cdot \text{number of new vehicles sold}\end{aligned} \tag{28}$$

$$\begin{aligned}&\text{Total emissions by vehicles that would not have been in use without PMET} =\\&\text{number of miles traveled} \cdot \text{existing emissions before PMET}\\&\cdot \text{sales lost due to PMET}\end{aligned} \tag{29}$$

It is assumed that VMT will not change for older vehicles due to the tax because it is assumed the cost of keeping older vehicles in operation is relatively insignificant and that consumers buy new vehicles for the amenities they offer rather than cost efficiency.

Equation (27) shows the calculation for pollution reduction used in the global optimization program. Current emissions indicate the emissions of new vehicles before either tax is imposed. These values are set to 2.1 grams of CO per mile for small cars, which is the ultra low emission vehicle (ULEV) standard for vehicles, 5.5 grams for pickups and SUVs, and 4.2 for all other vehicles in accordance with vehicle emission standards in place by 1992.

$$\begin{aligned}&\text{Pollution reduction in segment i} =\\&\text{cepm}_i \cdot Q_i^{\text{before PMET}} \cdot \text{C VMT}_i - (\text{VMT}_i \cdot \text{epm}_i) \cdot Q_i^{\text{after PMET}}\\&+ \text{C VMT}_i \cdot \text{mepm}_i \cdot \text{lostsales}_i\end{aligned} \tag{30}$$

For each ith firm, where cepm is the current emissions per vehicle, CVMT is the current vehicle miles traveled before the PMET, VMT is the new vehicle miles traveled, epm is the new emissions per vehicle, mepm is the emissions per mile from the oldest, non-gross polluting vehicles, and lostsales is the difference between sales in the segment before and after the PMET.

$$\begin{aligned}&\text{Total pollution reduction under PMET} =\\&\sum_{i=1}^{5} \text{Pollution reduction in segment i}\end{aligned} \tag{31}$$

Total pollution reduction is the sum of the pollution reduction achieved in each segment. Since the global optimization program requires variables to be of reasonably close scale, the pollution reduction figure in the optimization program is divided by one trillion.

EMISSION REDUCTION MECHANISMS UNDER THE LUMP SUM EMISSION TAX

Pollution reduction under the LSET is only achieved when automakers reduce the emissions characteristics of their vehicles. Since the LSET does not change the cost of travel, vehicle miles traveled (VMT) will not change.

POLLUTION REDUCTION CALCULATIONS UNDER LSET

Pollution reduction is calculated as the difference between total emissions before the LSET, less total emissions after the LSET for those who would have purchased a vehicle before the tax. This is the same group as was used for the PMET. Equation (31) shows the calculation for pollution reduction used in the global optimization program. Since the LSET does not change vehicle operating costs, vehicle miles traveled are unchanged from before the LSET was imposed.

$$\begin{aligned}&\text{Total emissions without LSET} =\\&\text{current vehicle miles traveled} \cdot \text{new per mile emissions} \cdot\\&\text{number of new vehicles sold}\end{aligned} \tag{32}$$

$$\begin{aligned}&\text{Total emissions after the LSET} =\\&\text{emissions from new vehicles} +\\&\text{emissions from vehicles that would not be in use but for the LSET}\end{aligned} \tag{33}$$

$$\begin{aligned}&\text{Emissions from new vehicles} =\\&\text{current vehicle miles traveled} \cdot \text{current per mile emissions} \cdot\\&\text{current number of vehicles sold}\end{aligned} \tag{34}$$

$$\begin{aligned}&\text{Emissions from vehicles that would not have been in use but for the LSET} =\\&\text{Current miles traveled} \cdot \text{current per mile emissions} \cdot \text{sales lost due to LSET}\end{aligned} \tag{35}$$

$$\begin{aligned}&\text{Pollution reduction in segment i} =\\&\text{cepm}_i \cdot Q_i^{\text{before LSET}} \cdot \text{C VMT}_i - (\text{CVMT}_i \cdot \text{epm}_i) \cdot Q_i^{\text{after LSET}}\\&+ \text{C VMT}_i \cdot \text{mepm}_i \cdot \text{lostsales}_i\end{aligned} \tag{36}$$

For each i^{th} firm, where cepm is the current emissions per vehicle, CVMT is the current vehicle miles traveled before the LSET, epm is the new emissions per vehicle, mepm is the emissions per mile from the oldest, non-gross polluting vehicles, and lostsales is the difference between sales in the segment before and after the LSET.

$$\text{Total pollution reduction} = \sum_{i=1}^{5} \text{Pollution reduction in segment i} \tag{37}$$

Total pollution reduction is the sum of the pollution reduction achieved in each segment. The pollution reduction figure in the global optimization program is divided by one trillion since the program requires variables to be of reasonably close scale. Now that pollution reduction under each tax has been calculated, the differences between total surplus under each tax will be calculated.

SOCIAL WELFARE CALCULATIONS

Consumer Surplus

Simple Walrasian surpluses were estimated from the linearized demand equations. However, since symmetric demands were assumed, this implies no income effect. Consequently, the Walrasian surplus measures of social welfare are identical to the compensated variation and equivalent variation measures of social welfare, and are determined in the following manner. Given the estimated demand curve for each of the five markets, the area under the relevant demand curve up to the point of equilibrium is calculated, as

Producer Surplus

Producer surplus is calculated as the difference between the price the producer receives and its marginal cost of production and any abatement cost. Marginal cost is assumed constant over the relevant range. The following equations show the calculation of producer surplus in the auto market for each segment before either tax and under the LSET and the PMET.

Surplus in the Travel Sector

Since the supply of travel is assumed perfectly elastic, there is no change in producer surplus under the PMET. To estimate consumer surplus in the travel sector, the travel demand function derived earlier will be used. Given the travel demand, consumer surplus (CS) before and after the tax can be calculated as follows:

$$\begin{aligned}&\text{Consumer surplus in travel market before PMET} =\\ &\frac{1}{2}\cdot(\text{intercept} - \text{price of travel})\cdot \text{VMT}_i^{\text{before PMET}}\cdot Q^{T}_{i,\text{before PMET}}\end{aligned} \tag{38}$$

Where VMT_i is the vehicle miles traveled in segment i, and the Q represents the quantity of new vehicles sold in the auto market.

$$\begin{aligned}&\text{Consumer surplus in travel market after PMET} =\\ &\frac{1}{2}\cdot(\text{intercept} - \text{price of travel})\cdot \text{VMT}_i^{\text{after PMET}}\cdot Q^{T}_{i,\text{after PMET}} +\\ &\frac{1}{2}\cdot(\text{intercept} - \text{price of travel})\cdot \text{VMT}_i^{\text{before PMET}}\cdot \text{lostsales}_i\end{aligned} \tag{39}$$

$$\begin{aligned}&\text{Total surplus in travel market after PMET} =\\ &\sum_{i=1}^{5}\text{Consumer surplus in segment i}\end{aligned} \tag{40}$$

where lost sales_i is the sales lost in segment i, and Q_i is new vehicle sales in segment i.

Tax Revenue

Anytime a tax is imposed, the gains from trade accrue not only to consumers and producers, but also to the government in the form of tax revenues. Since any tax revenue collected is revenue that could be redistributed to generate at least an equal amount of consumer surplus, tax revenue is included as part of the gains from trade for either tax. In fact, it has been argued that these tax revenues might produce a double dividend. A double dividend is believed to occur when a tax on a negative externality, such as pollution, not only reduces the undesirable activity but also generates tax revenue that can be used to reduce distortionary taxes in other markets. The case for the double dividend in environmental taxation has been made by Pearce, 1991. Pearce argues that carbon taxes could provide not only an environmental benefit, but allow taxes to be lowered on more elastic markets where welfare losses from taxes are higher. However, flaws in the double dividend approach have been found (Backhaus, 1995), (Schneider and Volkert, 1996), and some have argued that it could be negative (Bovenberg and Mooij, 1994). Therefore, since calculation of the double dividend would be problematic, any potential double dividend effect will be ignored.

Calculation of Tax Revenue under PMET and LSET

The PMET and LSET will each generate tax revenue. The following equations show the calculations used to estimate the amount of tax revenue in each market segment.

SOCIAL WELFARE UNDER PMET

To ascertain the social welfare impacts of each tax, total gains from trade under each tax are derived. Total gains from trade before either tax is imposed are simply the sum of the total surplus in each segment and total surplus in the travel market. However, the PMET tax revenues are multiplied by 10 to represent the 10 years of tax revenues that should be collected given that vehicles achieve the EPA's expected useful life of 10 years. For calculation purposes, any cost of tax collection is considered negligible. Therefore, total gains from trade under the PMET are calculated as:

$$\begin{aligned}&\text{Total gains from trade under PMET} = \\ &\text{total surplus in the automobile market} + \\ &\text{tax revenue each year under the PMET} \cdot \text{number of years tax collected} + \\ &\text{total surplus in the travel sector under the PMET} \cdot \text{number of years of vehicle travel}\end{aligned} \tag{41}$$

SOCIAL WELFARE UNDER LSET

In order to make a relevant comparison of the total gains from trade under the LSET and PMET, total gains from trade under the LSET must include the total surplus in the travel sector. Therefore, gains from trade under the LSET are calculated as:

$$\begin{aligned}&\text{Total gains from trade under LSET} = \\ &\text{total surplus in the automobile market} + \\ &\text{tax revenue each year under the LSET} + \\ &\text{total surplus in the travel sector under the LSET} \cdot \text{number of years of vehicle travel}\end{aligned} \tag{42}$$

NET DIFFERENCE IN SOCIAL WELFARE UNDER EACH TAX

The difference between the two surplus calculations in equations (41) and (42) show the advantage one tax has over the other in terms of social welfare when the demand curve, production costs, and level of pollution reduction are the same for each tax.

Optimization Program Calculation of Difference in Social Welfare

In addition to the constraints already mentioned, a few additional constraints were needed. Since upper and lower limits for computer optimization program were needed, upper-bounds of $1500 per gram of CO were placed on the LSET, and 25 cents per mile per gram of CO were placed on the PMET. Bounds of one million units per segment per quarter were placed on the quantities that each firm could produce. These bounds were non-binding and therefore did not affect the optimization results. Finally, pollution reduction was arbitrarily set at 40 trillion grams of pollution reduction. This is approximately a 20 percent reduction in pollution levels from new vehicles.

So far, travel demand with respect to per mile operating costs has been determined. Next, equations for net pollution reduction under the LSET and PMET were specified. Finally, consumer and producer surplus, tax revenue and total social welfare equations under each tax were created for the new automobile and travel markets. Next, the results of the computer program will be presented and analyzed using the equations and constraints defined earlier.

Optimization Results and Influencing Factors

In this paper so far, a computer optimization program was specified to determine the change in social welfare caused by the PMET and LSET for the same level of pollution reduction under each tax. Next, how consumer and producer behavior in response to each tax impacts social welfare will be discussed and the results of the optimization program will be examined.

SIMULATION RESULTS

Two sets of results from the simulation of social welfare were generated. The first set shows the minimum value of the expression:

$$\text{Total gains from trade under LSET} - \text{Total gains from trade under PMET} \tag{43}$$

Where

$$\begin{aligned}&\text{Total gains from trade under the LSET} = \\ &\text{total surplus in the auto market} + \\ &\ \text{tax revenue collected by the one time LSET} \\ &+ \text{total surplus in the travel sector} \cdot \text{number of years of vehicle travel}\end{aligned} \tag{44}$$

$$\begin{aligned}&\text{Total gains from trade under the PMET} = \\ &\text{total surplus in the auto market under the PMET} + \\ &\ \text{tax revenue collected each year by the PMET} \cdot \text{years tax collected} \\ &+ \text{total surplus in the travel sector under the PMET} \cdot \text{years of vehicle travel}\end{aligned} \tag{45}$$

The optimization program uses expression (43) to find conditions under which the PMET produces more gains from trade than the LSET. A positive value would indicate that the LSET produces more gains from trade than the PMET even under the best conditions. A negative value would indicate, given certain market conditions that the total gains could be higher under the PMET.

The second set of results from the simulation of social welfare show the minimum value of the expression:

$$\text{Total gains from trade under PMET} - \text{Total gains from trade under LSET} \tag{46}$$

The optimization program uses this expression to find conditions under which the LSET produces more gains from trade than the PMET. A positive value would indicate that the PMET produces more gains from trade than the LSET even under the best conditions. A negative value would indicate, given certain market conditions, that the total gains could be higher under the LSET. Table 2 shows the results of both the first set and second set of optimizations in millions of dollars. Consumer and producer surplus in each market under each tax when optimized for the LSET are shown, and consumer and producer surplus in each market when optimized for the PMET are shown.

The results in Table 2 show that when conditions are set favorably to the PMET, the optimization program finds the PMET produces more gains from trade in all but five quarters. In those five quarters, regardless of the own price and cross price elasticities used, the LSET reduces pollution by the same amount as the PMET but always with more gains from trade. For example, in the fourth quarter the 109 figure indicates the PMET produces at best $109 million less in gains from trade than the LSET even when the market conditions are optimized for the PMET. However, in most of the quarters the optimization program found market conditions where the PMET could be preferable to the LSET. For example, in the 32nd quarter when conditions are optimally set to the PMET, the PMET produces up to $225 million more in surplus than the LSET.

Table 2: Difference in Gains from Trade under each Tax

Quarter	Set 1: Optimized for the PMET	Set 2:Optimized for the LSET
32	(225)	(2,276)
31	(214)	(5,124)
30	(203)	(3,649)
29	(1,044)	(2,946)
28	168	(2,090)
27	(130)	(2,582)
26	(152)	(1,608)
25	(50)	(2,334)
24	(75)	(3,909)
23	(141)	(3,465)
22	(80)	(6,029)
21	(142)	(4,430)
20	(123)	(3,151)
19	(130)	(3,276)
18	20	(4,594)
17	(2,122)	(5,075)
16	13	(6,762)
15	(1,991)	(3,795)
14	(259)	(3,099)
13	(40)	(3,926)
12	(1,524)	(1,688)
11	(1,782)	(6,139)
10	(10)	(3,549)
9	73	(1,160)
8	(2,108)	(7,624)
7	(105)	(3,773)
6	(120)	(2,888)
5	(2,018)	(4,187)
4	109	(1,369)
3	(80)	(2,087)
2	N/A	N/A
1	(92)	(3,234)

These results show, in all but five quarters, either tax can be more efficient, given a certain set of market conditions. In the remaining five quarters, the LSET produces more gains from trade in this simulation. These results also show that when conditions are optimized for the LSET, the gap in gains from trade between the LSET and PMET can be very large, and when the results are optimized for the PMET, the gap in gains from trade between the two is relatively small. In fact, the average difference between the gains from trade is $470 million per quarter when optimized for the PMET, but almost $4 billion when optimized for the LSET.

Although it appears that the LSET is preferable to the PMET, this may not be the case. If market conditions are more favorable to the PMET then it will have better results than the LSET except in those five quarters when the LSET was superior regardless of market conditions. All the gap between two indicates is that it is possible that the gains from trade under the LSET will be much larger than gains from trade under the PMET if the true market conditions are closer to those found when optimizing the results for the LSET.

PMET and LSET Rates Needed to Achieve Desired Pollution Reduction

While the gains from trade calculations are the most important aspect of any economic analysis, it is sometimes difficult to relate how these figures really influence markets. Therefore, the median and lowest tax rates needed under the simulations to achieve the 40 trillion gram reduction in pollution are shown in Table 3. As stated previously, a 40 trillion gram reduction is approximately a 20 percent reduction in pollution levels.

The results in Table 3 show that in order to achieve the same level of pollution reduction, consumers will pay more under the PMET than the LSET over 100,000 miles of travel. Consumers discounting of future payments made under the PMET influence these results, but are not the only factor influencing these results. These rates are the tax rates that achieve the desired pollution reduction after adjusting for lost vehicle sales, among other factors. For example, these tax rates include the impact of vehicle sales being lost and a greater tax rate being imposed to counter-act the greater number of high emission vehicles remaining on the road.

With those caveats in mind, and assuming ten equal payments over ten years time for 100,000 miles of travel, comparing the taxes collected by the LSET and the PMET at the lowest rates for each, imply consumers discount the future at 14 percent. Comparing the median tax rates for each implies a discount rate of 41 percent. These results likely indicate consumers highly discount future payments. This makes particular sense to new vehicle purchases because many consumers hold on to a new vehicle for only a couple of years and do not care about any fees paid beyond their term of ownership. Further, they likely estimate that the resale price of their vehicle to any future buyer will not be severely impacted by the PMET. A high discount rate is important because it means consumers will not respond to the PMET as policy makers would intend. That is, the PMET does not cause consumers to demand lower emission vehicles. This explains the social welfare results found in earlier.

Table 3: PMET and LSET Tax Rates Needed to Achieve Desired Pollution Levels

	Median tax rate per gram of emissions	**Lowest tax rate per gram of emissions**
PMET for each mile traveled	0.00666	0.00179
PMET Total Paid after 100,000 miles	666.23	179.42
LSET Total One-time Tax	155.74	93.03

Summary and Conclusions

This paper applied Culp's method of estimating demand by assuming certain market structures and firm behaviors, and determining from firm behavior what the elasticity of demand must have been to explain both market price and each firm's output decision. Culp's first order conditions were adapted to reflect the impact of the PMET and the LSET given the specified abatement cost function. Next, the PMET's impact on consumer travel was estimated. Then, an optimization programs was used to compare the welfare impacts of each tax when the same level of pollution reduction was achieved under varying market conditions. Now, conclusions that can be drawn from the model will be discussed as well as the limitations of the model and areas for future research.

CONCLUSIONS BASED ON THE MODEL

The results found in this paper, while tending to favor the LSET, do not indicate which tax produces more gains from trade in every quarter. In addition, this paper found the potential welfare losses under the PMET are greater than under the LSET. The PMET depends on three key factors to achieve pollution reduction: the elasticity of vehicle demand, the elasticity of travel demand, and the sensitivity of consumers to vehicle operating costs. Each of these factors introduces an element of uncertainty into how the market will react to the PMET. These elements of uncertainty create opportunities for the policy to encounter conditions that are not favorable and could explain why the potential losses under the PMET are potentially so much greater in some quarters than under the LSET. In other words, because the effectiveness of the PMET depends on all these indirect and secondary incentives, and since the estimate of each varies, the optimization program found conditions where the PMET was extremely less effective than a LSET.

Summarizing, the problem with the PMET is that it seeks to reduce pollution by increasing the cost of travel; however, reduced travel is not the primary objective of the PMET—reducing emissions is the objective. Ideally, the PMET seeks to encourage manufacturers to produce low emission vehicles. If the goal is to encourage firms to produce low emission vehicles, does it make sense to tax the travel market? This seems like a rather indirect way of achieving the desired result. Further, if market conditions are unfavorable, the welfare losses could be much higher under the PMET than the LSET because the PMET can damage both the market for new vehicles and the market for travel.

While these results may just be a limitation of the model, this paper also reflects the difficulty of estimating the impact of the PMET. To implement either the PMET or the LSET the policy maker needs to know the own and cross price elasticity of demand. However, implementing the PMET additionally requires knowing both how consumer travel behavior will change, and how sensitive consumers are to vehicle operating costs. Because the potential welfare losses under the PMET could be much greater than under the LSET, policy makers hesitant to impose the PMET without better knowledge if market conditions are favorable its use.

LIMITATIONS OF THE MODEL

The analysis of the model is limited by the specification of a particular abatement function. Even if the specification of the abatement function is currently correct, it does not show the impact of technological change. It is reasonable to believe that firms would respond to either the PMET or LSET by researching new cost effective ways to reduce emissions. In the case of the PMET, firms might also attempt to reduce vehicle operating cost by methods other than reducing emissions, for example, firms might improve vehicle reliability.

Another limitation of the model is that in estimating firm reactions to the changes in demand caused by each tax, the marginal cost of vehicle production for all future units is assumed to stay the same as the last unit produced before each tax was imposed. This assumption could under or overestimate the actual production costs. In addition, since the model does not place any limits on capacity, as demand shifts from one vehicle segment to another in response to each tax the new production levels might exceed the capacity of the firms to produce. In addition, the model does not take into account the possibility that new firms might enter the industry and alter the cost of production.

This research is also limited by the use of linearized demand curves. While the revealed demand system used in this paper to estimate elasticities allows demand to take any form, linear or non-linear, the use of linearized demands to estimate post tax output levels and social welfare could cause problems. If the true demand relations are not linear, then as the new solutions get further away from the original output levels, the accuracy of the linearized demand curves will be reduced.

Finally, this research is limited by the lack of accurate data regarding the true marginal cost of vehicle production. With better information, the accuracy of the model would be improved and the estimates of demand elasticities would have narrower ranges.

AREAS FOR FUTURE RESEARCH

The revealed demand system used in this paper could also be applied to other oligopoly markets and products. It might be particularly useful in monopoly markets since the complexity of the model would be greatly reduced.

Further, this paper examined two market-oriented policy instruments aimed at the automotive sector, the LSET and the PMET. However, policy makers are also considering market-oriented producer or consumer subsidies, therefore research into these types of market-oriented solutions to the automobile pollution problem are needed. In addition, a better understanding of how market conditions influence the effectiveness of each tax and which market conditions favor the use of one tax over the other should be examined.

Finally, this paper shows that the PMET's losses could potentially be much larger than the LSET because the PMET depends upon indirect and secondary incentives to achieve its policy goal. Therefore, researchers should examine other areas of public policy for potentially large losses caused by policy makers' use of indirect or secondary incentives.

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