Heterogeneity of demand responses in modelling the distributional consequences of tradable carbon permits in the road transport sector

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Abstract
Personal road transport sector is one of the largest and fastest growing sources of CO_2 emissions. This paper investigates a tradable permit policy for mitigating carbon emissions from personal road transport and discusses various issues of permit allocation. As tradable permits will effectively raise the price of fuel, the policy has important distributional implications. The distribution of burden depends on permit allocation strategies and on the consumer response to an increase in price. The behavioural response may vary among different segments of the population depending on their travel needs, which in turn are contingent upon their income, location of residence and other factors. Consumer Expenditure Survey micro dataset from 1997 to 2002 has been used to econometrically model the possible variation of price elasticity for different socio-economic groups in the USA. Results indicate that the response of gasoline demand to a change in price does depend on income level or location of the household. Distributional impacts of the tradable permit policy are then evaluated using the micro dataset for year 2002. In this regard, different permit allocation schemes are considered in the analysis. Impacts on households owning a vehicle and households with no vehicles have been evaluated as well.

Introduction
Road transport is one of the major sources of CO_2 emissions in the United States. Although it is second in terms of total CO_2 emissions behind power generation, it has the highest growth rate. This unrestricted growth rate and the concern for security in oil supply have made gasoline demand management again an important policy question. In evaluating any policy to curtail carbon emissions from personal road transport or gasoline consumption, the distribution of burden becomes an important issue in political debate. In the past it was argued that gasoline taxes would affect the lower income households more than the wealthier households, although this view has been challenged recently. This paper focuses on tradable carbon permits in the personal road transport sector and evaluates the resulting distribution of burden on different socio-economic groups in the United States.

Policy brief
Raux and Marlot (2005) proposed a carbon permit trading system for the personal road transport sector following Fleming's (1996) domestic tradable permit proposal in the United Kingdom. The proposal includes allocating a specified amount of emission permits to members of the public. The permit credits are deducted from the buyers account (held on a permit debit card) electronically, in proportion to the carbon content of the fuel bought at the time of purchase. Transactions can be carried out through outlets such as top-up shops,[1] ATMs, petrol

1. Top-up shops are regular groceries, post offices, phone card shops and other retail shops, where pre-paid mobile phones or congestion charges (as in London)

retailers, and the internet. The price of the permits at any time would depend on the total number of permits available in the market and the demand for them at that time. The premium for permits will increase the perceived price of petrol and will be an incentive for users to pursue less emission intensive travel behaviour. This is essentially equivalent to a tax, except that a specified endowment of fuel is not taxed and that endowment can be sold if not used. Feldstein's (2006) proposal of tradable gasoline rights in the USA is similar.

Permit allocation is a critical issue in designing any tradable permit policy, as the allocation policy directly affects the distribution of burden from the policy. A free allocation to everyone means everyone has the right to emit some carbon[2] and thus the permits are given to everyone whether they drive a vehicle or not.[3] Another strategy is to sell permits to any user, but this implies people with more buying power have a greater right to pollute the environment. The present method of permit allocation in other environmental cap-and-trade programs (SO_2 emissions, lead phase down, air quality) is grandfathering or allocation on the basis of historical emissions. This can be done in the transport sector on the basis of past VKT/VMT, gasoline used, or even vehicle ownership. The right to emit carbon in all these cases lies with the current polluters, and bigger polluters are essentially rewarded for their polluting activities. Thus, from an environmental justice point of view, an equal and free allocation to all is the most equitable option.

Equal allocation to all results in a windfall profit to non-vehicle owning households, and this may result in significant opposition from existing fuel users. A middle of the road scheme is to retain the permits for non-vehicle owners by the government. This way, first-time buyers can get their due share of permits for free and will not face an entry barrier if they buy new vehicles. The remainder of the government-held allowances can be sold at the existing market price. The revenue thus collected by the government can be used to meet the administrative costs of implementation. Such an allocation, however, does not uphold the principle of equal rights to the environment.

A third option can be allocation on the basis of vehicle ownership. This allocation implicitly recognises that the right to emit carbon lies only with the vehicle owners, i.e. current polluters. We evaluate the distributional impact of all three allocation strategies in this short paper.

Measuring burden and demand heterogeneity

The loss in welfare as a result of a tradable permit policy can be measured from the change in consumer surplus, which requires the demand curve for carbon emissions or gasoline usage. In addition to the loss in consumer surplus, households will gain from the policy through the accumulation of wealth in the freely allocated permits. The change in welfare and the gains from permit together results in the total welfare change from the policy.

Different demand response for socio-economic groups may result in different changes in the consumer surplus. For example, if a household is naturally more responsive to a change in price of gasoline then its welfare loss will be less than those with more inelastic pattern of demand (Wadud et al. 2007a). Thus demand response for different socio economic groups needs to be determined in order to get a clear understanding of the distributional effect of a tradable permit policy in personal transport.

Gasoline demand model

Although gasoline demand is a widely researched topic, studies that quantify different demand pattern for various socio-economic groups are limited. Only two studies, West and Williams (2004) and Wadud et al (2007b) attempt to do so. West and Williams (2004) utilized consumer expenditure survey (CEX) micro data between 1996 and 1997 to derive a cross sectional model, whereas Wadud et. al. (2007b) uses CEX summary data for 5 income quintiles for 20 years. While West and Williams (2004) fails to utlize the time dimension, Wadud et. al. (2007b) is constrained by the representative agent assumption. In this paper, we utilize cross sectional time series data from CEX household level data, following Archibald and Gillingham's (1980, 1981) original formulation under the household production theoretic framework by Becker (1965) and Lancaster (1966).

To arrive at short to intermediate- term demand formulations, we opt for those households which have not changed their vehicle stock during the survey period. Our model is thus conditional upon fixed vehicle ownership. CEX reports households for four quarters only. Also the survey is a rolling one, which means each household is not interviewed at the same time, rather along different times, but at fixed intervals. The dataset therefore is an unbalanced one: while each household has four observations, they are not necessarily at the same time period. This leads to a dataset with a large number of cross sectional observations. We opt for a translog formulation[4] to model gasoline demand as a function of income (proxied by expenditure), price of gasoline, vehicle ownership, fuel economy, family size, and various interaction and dummy variables, which are explained in the result section.

Since the households in the CEX are random representative of US population, and we intend to derive demand for the population as a whole, like Archibald and Gillingham (1980, 1981), a random effect panel data model could be used. However the groupwise error term could be correlated to some of the explanatory variables, and we accomodate for this correlation using Hausman and Taylor's (1981) technique. In this, we assumed that the groupwise fixed effect term could possibly be correlated with the income variable and assumed all interaction variables with income to be correlated with this fixed effect. In choosing such a model we are inherently assuming that the households come from a homogeneous population and the sources of heterogeneity are adequately incorporated through the various interaction and dummy variables within the model.

can be credited to the account electronically.

2. From an ecological perspective this takes into account the natural carbon absorption ability of the ecosystem.

3. In theory, the best solution is for carbon permits to be traded between all sectors of the economy. The present analysis, however, only analyzes the personal road transport sector.

4. A translog demand in price and income: lngas = f{ln(income), (ln(income))2, ln(prc), (ln(prc))2, ln(income)*ln(price), other demographics}.

Table 1. Hausman-Taylor panel estimation results for gasoline demand#

Variable name and form	Explanation	Coefficient	Standard error
ln(exp)	Expenditure	1.146§	0.235
ln(prc)	Price of gasoline	-4.305§	1.172
ln(exp)*ln(prc)	Expenditure price interaction	0.118§	0.041
ln(prc)*ln(prc)	Price interaction	0.279§	0.115
ln(exp)*ln(exp)	Expenditure interaction	-0.089§	0.007
ln(car)	Number of car, SUV, light truck	0.223§	0.018
ln(mpg)	Average fuel economy of the household	-0.435§	0.027
ln(famsize)	Family Size	-1.527§	0.249
ln(prc)*ln(famsize)	Price family size interaction	0.078	0.044
ln(exp)*ln(famsize)	Expenditure family size interaction	0.155§	0.016
dfemale	Dummy for female head of households	-0.040§	0.009
dnonwhite	Dummy for non-white head of household	0.052§	0.015
drural	Dummy for rural location	-1.311§	0.452
ln(prc)*drural	Price and rural dummy interaction	0.223§	0.078
ln(exp)*drural	Price and expenditure interaction	0.033§	0.027
dmidwest	Dummy for midwest region	0.012	0.014
dsouth	Dummy for southern region	0.078§	0.013
dwest	Dummy for western region	-0.027	0.014
dschool	Dummy that household head has been to school	0.024	0.014
dsomcol	Dummy that household head has some college experience	0.008	0.015
dcolgrad	Dummy that household head is a college graduate	0.009	0.014
dle25	Dummy that household head is less than 26 years old	0.053§	0.022
d2544	Dummy that household head is 25 to 44 years old	0.043§	0.010
dge65	Dummy that household head is older than 64 years	-0.186§	0.012
othvehno	Number of other vehicles (motor cycles, boats, etc.)	0.097§	0.021
ln(prc)*dmulcar	Price and multiple vehicle ownership interaction	-0.125§	0.030
ln(exp)*dmulcar	Expenditure and multiple vehicle ownership interaction	0.086§	0.017
time	Time in months	0.0000	0.0002
dearn0	Dummy for no full time worker	-0.126§	0.011
dearn2	Dummy for 2 full time worker	0.023§	0.009
dearn3	Dummy for more than 2 full time worker	0.031§	0.015
dchild1	Dummy for the presence of 1 children	-0.037§	0.014
dchild2	Dummy for the presence of two children	-0.100§	0.018
dchild3	Dummy for the presence of more than two children	-0.170§	0.024
Constant		12.224	3.276

#There were 11 monthly dummies as well, results not presented here § Statistically significant at 95 % confidence level

Results

Results from the econometric estimation of the gasoline demand model are presented in Table 1. Since the model contains interaction terms with price and income, the corresponding elasticities are not directly evident and are separately calculated at the mean values of the variables in Table 2. A few results are worth mentioning. Firstly rural households consume more gasoline than urban households.[5] but are less responsive to a price change, since they have fewer alternate modes available. This result confirms Wadud et al (2007b) results from aggregate estimation. Rural household's response to a change in income, however, is not statistically different (at 95 % confidence level) from the urban households. An increase in family size increases gasoline consumption, yet households' response to a change in gasoline price does not differ in a statistically significant way (at 95 % level) with increased household size. Higher number of working residents increases consumption, whereas presence of children reduces it.[6] Higher fuel economy reduces consumption and higher vehicle ownership has the opposite effect. Multiple car owning households have higher response to a price increase. This may be explained by their opportunity to switch to the more fuel efficient vehicle. Although our price elasticity estimates are at the higher end, they are well within the range reported in literature that use household level data.[7] Our income elasticities also are in agreement with income elasticities from hosuehold level data.[8]

The results for the distribution of welfare for a hypothetical 15 % reduction in carbon emissions for different income quintiles are presented in Tables 3, 4 and 5 for different allocation of permits. The price of permits can be determined from the aggregate demand curve and given reduction in gasoline consumption or carbon emissions (Wadud et al. 2007a). Since we did not determine an aggregate demand model separately, we used trial and error method using different permit prices and total consumption reduction, until they converge to a 15 % reduction. This corresponds to a permit price is USD 0.85 per gallon of gasoline or USD per tonne of carbon reduction. The excessively high price of carbon permits is a result of relative inelasticity of gasoline demand and trading taking place within a single sector.

Table 3 presents the result for equal allocation to everyone. A policy is said to be progressive if successively higher income

5. Since we used interaction terms with rural dummy, the effect of rural location is not the coefficient of rural dummy alone, but it is: coeff[rural dummy] + coeff[rural dummy*lnprice] * average lnprc + coeff [rural dummy*lnincome] * average lnincome, see Table 2.

6. A 2 person household with 1 adult and 1 child possibly is expected to have less demand for gasoline than a 2 adult 0 child household.

7. e.g. West and Williams (2004) reported a price elasticity as high as -0.69 using household level data.

8. e.g. Archibald and Gillingham (1981) reported an income elasticity of 0.29 for one-car households.

Table 2. Elasticy estimates from the econometric model for a two person, single earner family at mean income and mean price (standard errors in paranthesis)

Elasticity with respect to	Household type	Elasticity
Price	Urban single car	-0.402 (0.032)
Income	Urban single car	0.257 (0.013)
Price	Rural single car	-0.179 (0.079)
Income	Rural single car	0.291 (0.028)
Price	Urban multicar	-0.527 (0.030)
Income	Urban multicar	0.343 (0.012)
Price	Rural multicar	-0.304 (0.076)
Income	Rural multicar	0.377 (0.026)
Rural		0.103 (0.016)
Family size		0.243 (0.015)

Table 3. Distributional burden from equal per capita allocation (standard errors in paranthesis)

	Mean of ratio of welfare change to expenditure				
	Lowest quintile	Second quintile	Third quintile	Fourth quintile	Highest quintile
Vehicle-owning households	0.111 (0.029)	0.295 (0.029)	-0.036 (0.021)	-0.194 (0.015)	-0.281 (0.011)
Non-vehicle owning households	3.982 (0.639)	2.479 (0.058)	1.658 (0.091)	1.264 (0.124)	0.401 (0.110)
All households	0.890 (0.132)	0.854 (0.029)	0.108 (0.021)	-0.152 (0.016)	-0.266 (0.011)

Table 4. Distributional burden from equal per capita allocation, but government retains non vehicle owners' permits (standard errors in paranthesis)

	Mean of ratio of welfare change to expenditure				
	Lowest quintile	Second quintile	Third quintile	Fourth quintile	Highest quintile
Vehicle-owning households	0.111 (0.029)	0.295 (0.029)	-0.036 (0.021)	-0.194 (0.015)	-0.281 (0.011)
Non-vehicle owning households	-0.682 (0.051)	-0.348 (0.026)	-0.527 (0.051)	-0.431 (0.055)	-0.694 (0.099)
All households	-0.049 (0.026)	0.131 (0.023)	-0.077 (0.020)	-0.201 (0.015)	-0.291 (0.011)

Table 5. Distributional burden from equal per vehicle allocation (standard errors in paranthesis)

	Mean of ratio of welfare change to expenditure				
	Lowest quintile	Second quintile	Third quintile	Fourth quintile	Highest quintile
Vehicle-owning households	0.202 (0.029)	0.315 (0.028)	-0.011 (0.020)	-0.087 (0.016)	-0.102 (0.012)
Non-vehicle owning households	-0.682 (0.051)	-0.348 (0.026)	-0.527 (0.051)	-0.431 (0.055)	-0.694 (0.099)
All households	0.024 (0.025)	0.145 (0.022)	-0.055 (0.019)	-0.097 (0.015)	-0.116 (0.012)

quintiles share a greater burden in proportion to their income. Following this definition, the tradable permit policy is regressive among households with vehicles between the lowest and second lowest income quintile, and progressive otherwise. Households who do not have any gasoline consumption gain from the policy because of the free allocation of permits. The gain is strictly progressive as lower income households always gain more as a proportion of expenditure than the higher income ones. Combining the households, for the entire population, the policy is strictly progressive. The regressive effect in the lowest and second lowest income quintile among vehicle-owning households has been overshadowed by the fact that a greater proportion of households in the lowest income quintile do not consume gasoline and therefore gain more from the policy.

When government retains non-vehicle owners' permits, households that do not own a vehicle but still consume gasoline (say, through renting a vehicle) are in a disadvantageous position as they do not gain any free allocation (Table 4). The non-vehicle owning households in the lowest and highest income quintile share the highest burden. When considering all households together the allocation is regressive among the two lowest quintiles, and progressive thereafter.

A per vehicle allocation scheme benefits the households with vehicles (Table 5). Since most households in the highest income quintiles are multiple vehicle owning households, these households' loss in welfare is much less as compared to a per capita allocation. For all households, it is regressive among the two lowest income quintiles and progressive after that.

Conclusion

In this paper, we evaluated the distributional burden of a carbon trading policy in the personal tradable sector in the USA. To account for the natural response of households to an increase in price, we modelled demand for gasoline using CEX micro dataset from 1997 to 2002. Various interactions between the variables allowed us to model different response among different types of households. We found that rural households and households with multiple vehicles are more responsive to a price change than urban and single-vehicle households, respectively.

Using the gasoline demand model, distributional burden for a hypothetical emissions reduction of 15 % has been modelled for vehicle owning households, non-vehicle owning households and also all households together for three different allocation strategies. All three allocation strategies are regressive between the lowest two income quintiles for vehicle owning households, although these households always have a positive gain from the policy.[9] Households in the highest income quintile face the least welfare loss when permits are allocated on a per vehicle basis. However, a per vehicle allocation results in a heavy burden for households that do not own a vehicle, yet have some gasoline consumption through rented vehicles. Only a per capita allocation is strictly progressive when all households are considered together. Care should, however be taken to interpret the results, as we consider only the direct welfare loss due to reduced consumption, and, there may be significant localized effect in terms of mobility, which is not captured by reduced consumption alone.

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9. They are regressive as households in the second quintile gain more than those in the lowest quintile.