What drives gasoline taxes?

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Abstract

Gasoline taxes are the most important tax on car use. The question naturally arises as to what toll would be adopted by a government that responds to the preferences of the public. To address that issue, we begin with the standard Downsian model, where policy is set by the median voter. This model predicts that as long as the median voter is not a car user, he wants high taxes on road use and on road capacity that maximize revenues. Whenever he becomes a driver himself, he wants road user taxes that are lower and only increase to control congestion. We then use panel data for 28 countries and find support for our theory. When the median voter becomes a driver, the gasoline tax drops on average by 20%.

Keywords: gasoline taxes, median voter theory, political economy

JEL-classification: H23, R48, Q48, L98, Q52

1. INTRODUCTION

Both political and economic factors likely influence tax policy in democratic regimes. It is interesting to consider what gasoline taxes would be adopted when governments can be considered to simply respond to the preferences of their electorate. Can we expect that gasoline taxes change over time as a result of a change in the relative position of cars, from luxury for some to a generalized consumption good? Luxury goods are taxed by the poor majority, whereas, once the majority are car owners, the tax can reduce the externalities generated by road use, particularly congestion. We treat this question both theoretically and empirically, using international panel data to test a simple theory based on the standard Downsian model, where policy is set by the median voter .

The Downsian model can apply both to elections in which two candidates vie for election, and to referenda. A potential limitation of the Downsian model is that it may apply only to a single issue, with single-peaked preferences. But we shall see that under reasonable assumptions, the Downsian model can apply when voters must decide both on users fees and on investment in road capacity. In the model individuals differ only in their relative income level and this income level will determine their demand for car use and their benefit of road use and of road investments. Comparative statics of this simple model (varying aggregate income levels) generate interesting predictions that may explain the decline of real gasoline taxes over time. More precisely one can predict that at the time the median voter becomes a car owner, the tax on gasoline declines.

Our conclusions would also apply under other views of elections. In particular, under our assumptions the citizen-candidate model (see Besley and Coate (1997) could have the median voter run for office, win election, and determine policy. And rather than let any policy be allowed on the agenda, we could extend the model to consider an agenda setter (as in Romer and Rosenthal (1979)). The toll would then not be the one preferred by the median voter; but the qualitative results, such as that the toll will be higher if the median voter is a driver than if he is not, will continue to hold.

In the empirical setting, the determinants of gasoline taxes are of course more complex. Based on theory from Persson et al. (2000), Fredriksson and Millimet (2004) use the propensity scoring method to examine whether differences in gasoline taxes between countries could be explained by them being a presidential or a parliamentary regime. They find that on average presidential regimes have lower taxes than parliamentary ones. Besley and Rosen (1998) examine vertical tax externalities by looking at the effect of US federal taxes on state gasoline and cigarette taxes. Goel and Nelson (1999) extend the Hettich and Winer (1988) vote maximising model of how politicians change tax structure in response to change in pre-tax prices. An empirical test also using US panel data indicates that state gasoline taxes decline with pre-tax gasoline prices. In a mainly empirical analysis, Hammer et al (2004) apply panel data from 21 OECD countries and conclude that higher gasoline consumption leads to lower taxes. Rietveld and Van Woudenberg (2005) use cross section data to explain taxes via fuel price differences between countries. Results are reported separately for diesel and gasoline. In Europe, a higher gross national product per capita and higher government expenditure per capita are associated with higher fuel taxes, but there is no sign that negative externalities lead to higher taxes. Decker and Wohar (2007) look at the diesel tax rather than gasoline and so concentrate on freight (US trucking industry). In this case industry employment is the significant explanatory variable: the higher the proportion of freight trucking employment in a state, the lower the diesel tax.

Our approach is consistent with the previous empirical analysis but differs in several ways. Our simple political economy theory allows us to examine the evolution of gasoline taxes with real income (over time), rather than testing a static model. The number of road users (gasoline consumption) is determined by the preferences of the median voter, given pre-tax price, average income level and road network capacity, In this setting, changes in gasoline taxes can be considered to represent governmental response to the preferences of the median voter as a private road user. Diesel, on the other hand, is also more widely used for freight transport. For this reason, we prefer to restrict the empirical analysis to gasoline taxes only. The empirical test is applied to 28 democratic countries, controlling for pre-tax price, as this does not remain constant over time, but other possible determinants, including the structure of political institutions are accounted for in country specific fixed effects.

In Section 2 the theoretical model is developed, the empirical analysis is described and discussed in Section 3 before Section 4 concludes.

2. MEDIAN VOTER MODEL

2.1. *Theoretical Framework*

Consider an area where road capacity is given at a level K and where congestion is more or less homogeneous in the whole area. Assume further that the location of activities is fixed.

Each of a large number, N, of individuals ($n=1,..,N$) has a share α_n in total income Z. The richest individual has index 1, the poorest index N. Each of the individuals can choose to own and use a car or not. Let $U(x,d)+W(E)$ be the direct utility of an individual. It is a function of the consumption of other goods x and the use ($d=1$) or not ($d=0$) of a car. It also depends on the supply of public goods E that are not transport related. We assume that the non transport related public goods are additively separable from the utility of driving. All goods are normal goods.

Let the price of the consumption good be 1 and let the cost of driving be

$$p_d = a + \tau + bT\left(\frac{D}{K}\right) \tag{1}$$

where a is a fixed resource cost of owning a car, τ is the tax on car ownership and use, and the last term represents the user time cost of using a car and this is a function of the ratio between total number of car users D and the road capacity K.

Consider first the choice of one individual. He decides to own a car and use it if this generates for him a higher utility. He solves the following problem:

$$\begin{aligned} &\text{Max U(x,d)} + \text{W}(\text{E}) \\ &\text{subject to } x + p_d d \le \alpha_n Z \qquad (2) \\ &d \text{ is integer variable} \end{aligned}$$

Once d has been chosen, the rest of the income is spend on the consumption good x so that the solution of this problem can be characterised by car ownership as function of total cost and income: $d(p_d, \alpha_n Z)$,that we assume is continuous and twice differentiable. The decision to own a car will be a function of the price and the income level. The total number of drivers D equals

$$D = \int_1^N d(p_d, \alpha_n Z) dn \le N \qquad (3)$$

As owning and using a car is a normal good we have that $d(p_d, \alpha_{n-1} Z) \ge d(p_d, \alpha_n Z)$ so when a given individual prefers to own a car, all individuals with higher income (lower index) will also own a car.

We can now introduce a government budget constraint and a political decision making process. We assume a simple set up: government has to pay for general expenditures E and for roads that have a rental cost r and has to finance the expenditures by a proportional income tax t and by the car tax τ. The government budget equation is:

$$tZ + \tau D = rK + E \qquad (4)$$

We assume that the proportional income tax t, the level of other expenditures E and the road capacity have all been fixed. We relax the fixed road capacity assumption later. Keeping the income tax rate t and other expenditures fixed means that we see the politicial process as a process in different stages where at one stage one decides on income tax levels and other public goods and at another stage one decides on road use related taxes. We assume that the road taxes are decided by simple majority voting and leave the rest of the political system unspecified[2]. To balance the government budget equation we assume moreover that the government expenditures remain fixed and that the budget is balanced by a lower income tax. These assumptions reduce the political decision to one dimension: the level of the tax on car use knowing that the revenues are returned under the form of lower income taxes. If preferences of each individual over the car use tax are single peaked[3] we can study the political equilibrium by analysing the preferences of the median voter.

When the median voter has to decide on the car tax he has to compare two options: either he prefers to own a car and then he decides on the optimal car tax given that he also has to pay the tax, or he prefers not to own a car, and then he decides on the optimal tax level differently.

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[2] One could also study the structure of taxes and level of non-road public goods as in Gevers and Proost (1978).

[3] This can be guaranteed using additional restrictions on preferences.

2.1.1. *Median voter does not drive*

Assume first that the median voter prefers not to drive. Let the income of the median voter be $\alpha_{med}Z$. Then he selects the car tax level τ^0_{med} that maximizes the following expression:

$$U\left[\left(1-\frac{rK+E-D\tau}{Z}\right)\alpha_{med}Z,0\right]+W\left[E\right] \quad (5)$$
$$subject\ to\ n<N/2$$

and this gives an optimal car tax level in the unconstrained case:

$$\tau^0_{med}=-\frac{D(\tau)}{\frac{\delta D}{\delta\tau}}, \quad (6)$$

which is the tax revenue maximising level of car taxes. The intuition is straightforward: the median voter is not a car owner so he prefers to minimize his own income tax payments.

2.1.2. *Median voter drives*

Now consider the case where the median voter prefers to own a car. Then his choice of tax rate τ^1_{med} involves a more difficult trade off as he seeks to maximise (subject to *n>N/2*):

$$U\left[\left(1-\frac{rK+E-D\tau}{Z}\right)\alpha_{med}Z-\left(a+\tau+bT(\frac{D(\tau)}{K})\right),1\right]+W\left[E\right]. \quad (7)$$

This leads to

$$\frac{1}{U'}\frac{\partial U}{\partial \tau} = \underbrace{\alpha_{med}\left(D + \tau\frac{\partial D}{\partial \tau}\right)}_{\substack{median\,voter\\ share\,in\,revenues}} \underbrace{-\left(1 + \frac{b}{K}\frac{\partial T}{\partial D}\frac{\partial D}{\partial \tau}\right)}_{\substack{median\,voter\,costs\\ =toll\,payment\\ -benefit\,of\,reduced\,congestion}} = 0 \tag{8}$$

which implies the following optimal tax on car use

$$\tau^{1}_{med} = \frac{D(\tau)}{-\frac{\partial D}{\partial \tau}} - \frac{1}{\alpha_{med}(-\frac{\partial D}{\partial \tau})}\left(1 + \frac{b}{K}\frac{\partial T}{\partial D}\frac{\partial D}{\partial \tau}\right). \tag{9}$$

The optimal tax is now equal to the monopoly charge (first term) minus a correction. This correction is in principle negative because the time gain of reduced congestion is always smaller than the tax[4]. This implies that the tax preferred by the median voter is lower than the tax preferred by the non drivers. The correction term will become more important when the share of the median voter in the overall tax revenue refunds α_{med} becomes smaller. In an extreme case with a very low share in total income for the median voter, it is possible that the tax on gasoline becomes actually negative so that gasoline is subsidized. Consider an increase in the share of total income (and income tax payments) of the median voter α^{med}, if he continues to prefer owning a car, this will increase the tax rate on car use:

$$\frac{\partial \tau^1_{med}}{\partial \alpha_{med}} = \left(\frac{1}{\alpha_{med}}\right)^2 \frac{1}{-\frac{\partial D}{\partial \tau}} > 0 \tag{10}$$

So a relatively richer median voter has a larger share in the income tax revenues but also a larger share in the income tax refunds made possible by an increase in the tax on car use.

2.1.3. Endogeneous road capacity

Up to now, capacity has been kept fixed when the political process decides on the level of road use tax. Consider first the case where the median voter prefers not to be a driver. Then he maximizes ((5)) using two instruments: the car use tax and the road capacity K. This gives the following optimal conditions (using °° to denote the best choices):

$$\begin{aligned} \tau^{00}_{med} &= -\frac{D(\tau^{00}, K^{00})}{\frac{\partial D}{\partial \tau}} \\ r &= \tau^{00} \frac{\partial D(\tau^{00}, K^{00})}{\partial K} \end{aligned} \tag{11}$$

[4] A sufficient condition is that the demand function for car ownership is downward sloping in n and the average cost of owning a car upward sloping in n.

This is the traditional condition for the optimal capacity choice for a monopolist when user charges can be varied. Capacity will be increased as long as this generates extra revenues. The tax on car use is now also a function of the road capacity.

When the median voter prefers to be a driver, the conditions for optimal taxes and capacity are more complex. Maximizing ((7)) we obtain (where superscript 11 stands for optimal choice):

$$\tau_{med}^{11} = \frac{D(\tau^{11}, K^{11})}{-\frac{\partial D}{\partial \tau}} - \frac{1}{\alpha_{med}(-\frac{\partial D}{\partial \tau})}\left(1 + \frac{b}{K^{11}}\frac{\partial T}{\partial D}\frac{\partial D}{\partial \tau}\right) \tag{12}$$

$$\left(-r + \tau^{11}\frac{\partial D}{\partial K}\right)\alpha^{med} = \frac{bT'}{(K^{11})^2}\left[K^{11}\frac{\partial D}{\partial K} - D(\tau^{11}, K^{11})\right]$$

The first condition is the same user tax condition as before but now evaluated at the optimal capacity. The left hand part of the second condition in ((12)) represents his share of the net revenues generated by a capacity extension. When the median prefers not to drive the left hand side of this second condition equals zero (cfr. ((11))) as this maximizes the net revenues. When the median prefers to drive, he is also concerned by his own user cost and the right hand term is the decrease in user cost associated with a small increase of capacity. It consists of the time gain associated with an increase in capacity minus the time loss associated with the induced use. When capacity is chosen optimally by the user, the right hand term is expected to be negative and there is always a net gain to the user of an increase in capacity. With decreasing marginal user benefits of capacity extension, the optimum road capacity needs to be larger. The result is that, for a given user tax, the road capacity is expected to be higher when the median voter drives. However, the larger his share α^{med} in total income, the larger his share in road capacity costs and in the toll revenues; he will be opposed both to a road budget deficit that is too large and to too much expansion of road capacity.

2.2. Comparative statics and change over time

We are interested in knowing how the user tax and capacity evolve over time when overall income grows. For constant costs of road building, we can consider the following comparative static exercise. Assume that aggregate income increases and that the share of the median in the total income remains constant when income increases. As using a car is a normal good, one can expect that the number of drivers increases with income. As long as the median voter prefers not to drive, the tax on car use will maximise revenues and road capacity will be decided as a function of this objective. If there are constant returns to scale in road construction[5], as we assume, and road capacity is continuously updated, one can expect an increasing tax on car use as overall income grows. This is our first testable proposition:

PROPOSITION I: When the median voter prefers no to drive, when his share in total income remains constant and when capacity and user tax can be varied continuously, an increase in total income leads to an increase in the tax on road use.

This result can be easily shown using Figure 1. In this figure we represent the upward shift in demand for owning and using a car $D(p_d,Z)$ when income increases from $Z°$ *to* $Z°+\Delta$. We also represent the marginal user cost before taxes. This is a long run user cost function that is a function of the ratio between demand for car use and capacity. When there are constant returns to scale for road construction and maintenance, the long run user cost function including the external congestion tax is constant and there is full cost recovery of capacity costs by the external congestion tax[6]. Consider now a median voter that wants to maximise net revenues from road use charges. He will select a number of drivers for which the marginal user cost (including the external congestion tax) equals the marginal revenue (MR). As the demand function rotates upward, this implies that the tax on car use has to rise.

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[5] See Small & Verhoef (2007, p112) for evidence on economics of scale in road construction.

[6] This follows from the fact that the user cost function is homogeneous of degree zero in the ratio D/K and that the rental cost of capacity is assumed constant.

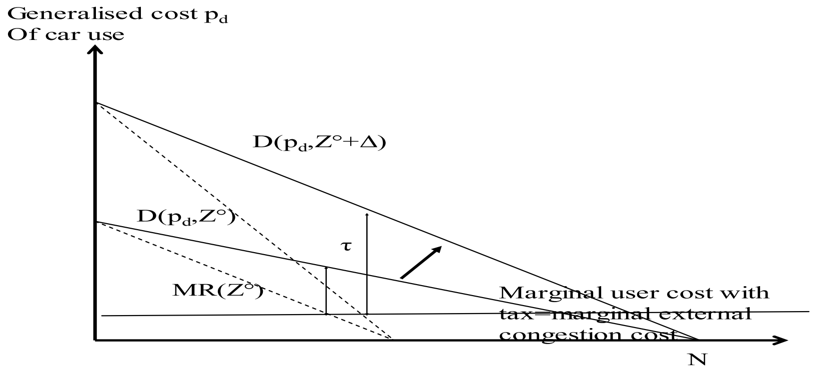

Figure 1 Effect of an increase in average income when the median voter prefers not to be a driver

The second proposition deals with the transition of the median voter from non-driver to preferring to drive.

PROPOSITION II: When the median voter prefers to drive, when his share in total income remains constant and when capacity and user tax can be varied continuously, the tax on road use will drop and road capacity will increase. An increase in total income leads to an increase in the tax on road use.

A general proof of this proposition is rather tedious as it depends on the distribution of income in the population (determines the slope of demand function ((3)), on the structure of the utility function and on the functional form of the average cost function ((1)). We sketch here a proof that works for a linear function demand function *d()* and a linear average cost function. In that case we can show that a median voter who drives prefers a lower tax and a higher capacity by using Figure 2. First, we see that, for given capacity *K*, a median voter who drives always prefers a lower tax on road use than when he would not be a driver so the curve $\tau°$ *(K)* lies above τ^{med} *(K)*. This follows from comparison of ((11)) and ((12)). In addition we know that τ^{med} *(K)* is downward sloping in K.

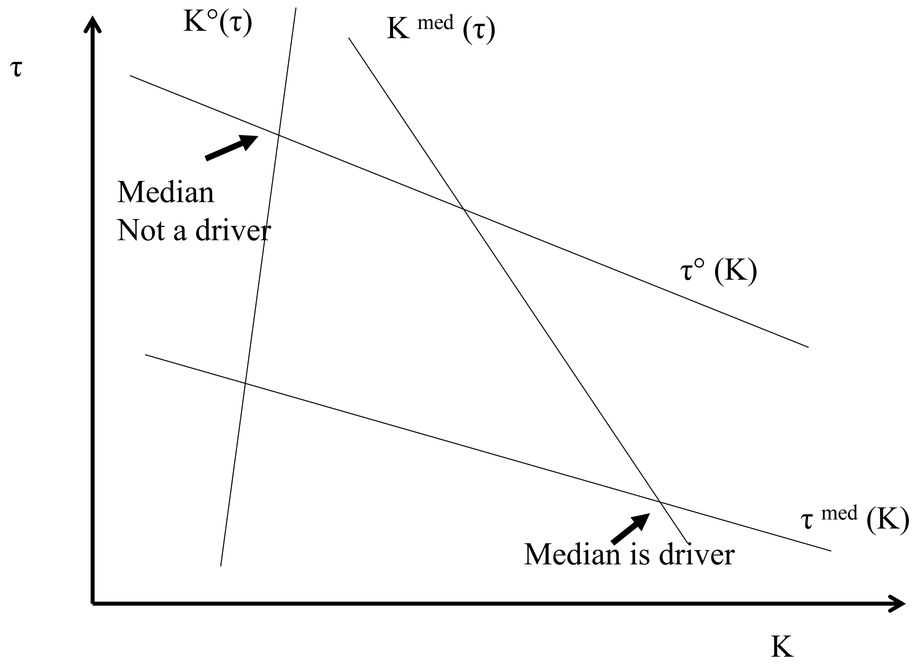

Figure 2 Difference in user tax and capacity between a median who prefers to drive and a median who prefers not to drive

For given road user toll, the optimal road user capacity $K°(\tau)$ when the median voter prefers not to drive is always smaller than when he prefers to drive $K^{med}(\tau)$. In addition, $K^{med}(\tau)$ is decreasing in τ. The result is that the solution $\tau°$, $K°$ preferred by a median voter who is not a driver has always a larger road tax and a smaller capacity than when the median voter prefers to drive.

To see the effect of an increase in average income when the median is a driver, continue to use a linear demand and average cost function. Starting with the optimal tax when the median voter is a driver and keeping capacity constant, an increase in the average income level will increase the number of drivers. In the expression for the optimal user tax (first line in ((12))), we see that the first part of this expression related to the revenue generating function of the user tax, increases while the second (negative) part stays constant. So the optimal tax has to increase.

This could give a profile for user taxes as presented in Figure 3. At low aggregate income levels, the median voter is not a driver and favours the revenue-maximizing toll. When aggregate income rises, the number of users will rise and so will the toll. Once a certain level of income is reached, the median voter's valuation for a trip has become so high that he also wants to drive, and this means he favours a lower toll. When income continues to grow, the number of drivers keeps increasing and the median voter favours an increase in the toll.

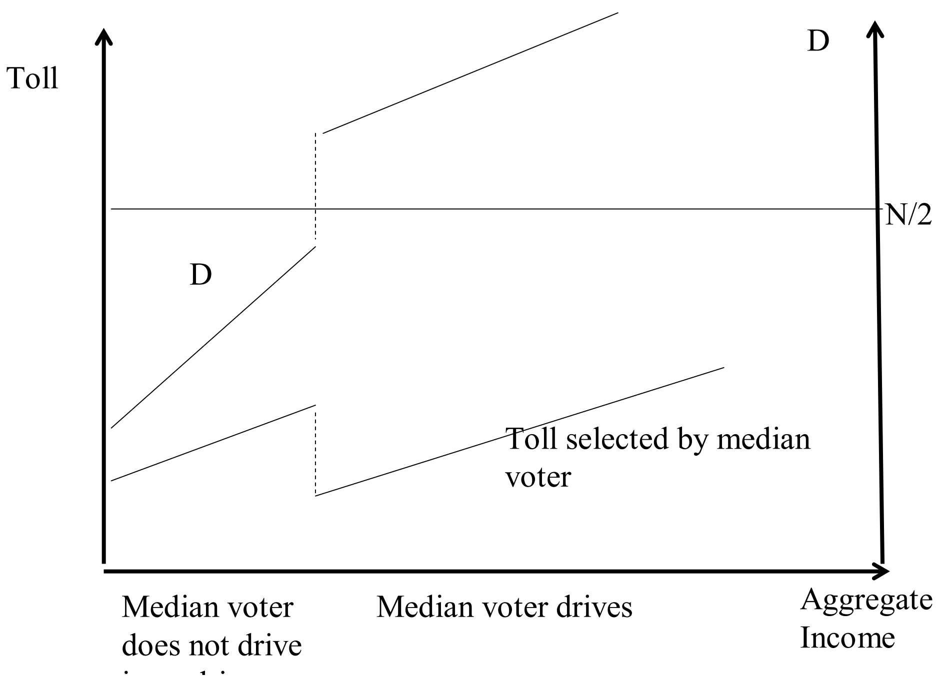

Figure 3 Effect on toll levels of an aggregate increase in aggregate income when capacity can be continuously adapted

Another candidate for comparative statics is the pre-tax price of gasoline. As oil prices have shown significant variations, this can be important. The pre-tax gasoline price enters the theoretical model via the pre-tax cost of driving parameter, *a*, in (1). If the median voter prefers not to drive, an increase in the pre-tax price increases the marginal user cost before tax. When tax revenue is the objective, the tax on gasoline will decrease when the pre-tax price increases. This leads us to Proposition 3.

PROPOSITION III. When the median voter prefers not to drive, an increase in the pre-tax price of gasoline leads to, ceteris paribus, a reduction in the gasoline tax.

The proof is straightforward and comes down to an increase in the marginal user cost before tax shown in Figure 1. When demand functions and marginal cost functions are linear, half of the pre-tax price increase would be absorbed in this case of pure moonopoly pricing.

PROPOSITION IV. When the median voter becomes a driver, an increase in the pre-tax price of gasoline leads to a decrease in the gasoline tax he prefers.

This can be shown using ((12)). An increase of the average cost implies that the first component of the user charge, the revenue raising component decreases because demand is lower. The second component is constant for linear demand and average cost functions. So the gasoline tax will increase but probably less than in the case the median voter is a driver.

3. EMPIRICAL ANALYSIS

3.1. Data

In this section, we test whether the median voter model provides a plausible explanation of national policy on taxes for road use by non-commercial vehicles using international panel data. The dataset covers 28 mainly OECD countries[7] for the period 1978-2005. In most countries, taxes on road use by non-commercial vehicles consist of fuel taxes and annual vehicle taxes. Although diesel is being increasingly used by car drivers, particularly in Europe[8], we limit our study to gasoline taxes as these are only imposed on private vehicles and do not extend to commercial vehicles as is the case with diesel. It is reasonable to assume that the behaviour of voters who choose to drive (or not to drive) gasoline cars will be representative of the voting population as a whole. It would be useful to include annual vehicle taxes, as these appear to differ widely between

[7] Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy Japan, South Korean, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland, the United Kingdom and the USA

[8] According to Eurostat data, in 2000, more than 30% of cars used diesel in Austria, Belgium, France, Luxembourg and Spain. In other countries, usage was less than 15%.

countries[9] and depend on vehicle characteristics (vehicle size, power etc), which can be considered to be indicative of environmental preferences. However, these tax data were only readily available from 2001 onwards[10], a small part of our sample period, and were therefore not used. As long as their structure does not change, these will be captured in the country fixed effects that we will introduce later.

The fuel tax data are total taxes combining excise, VAT, local and federal level taxes, where applicable. Gasoline tax and pre-tax gasoline price data in national currencies per litre were obtained from the IEA (refs for online database and reports). Where different grades of gasoline were available, a simple average has been taken. The GDP per capita data, which is used to represent aggregate income, and conversion parameters (CPI and PPP exchange rates) are taken from the OECD Factbook 2007 (online). All data have been converted to US dollars at year 2000 prices. However, a number of limitations to the dataset should be noted: data was not available for all countries for each year and there was limited tax data for South Korea (2000 on only). For several countries, the conversion to real data resulted in inflated values for a number of years. This could be due to the relatively low average income in these countries or because they were in a

[9] A rough calculation based on total annual vehicle taxes per country for 2000 (source TREMOVE) indicates that vehicle taxes are a similar order of magnitude to gasoline taxes except for Luxemburg, Portugal and Spain, where the ownership tax was very low.

[10] Source ACEA

period of political transition. Data were therefore excluded for Spain before 1986, Portugal before 1990, Greece before 1992 and for Mexico, the Czech Republic, Hungary, Poland and Slovakia before 1995.

3.2. *The empirical model*

Propositions 1 and 2 from the Section 2 indicate that taxes on road use generally increase as aggregate income increases, assuming income distribution remains fixed. When a certain average income level is reached, the median voter prefers to drive and there is a drop in road tax (see Figure 2). This hypothesis can be tested empirically using an econometric model.

$$\tau_{i,t} = \theta\tau_{i,t-1} + \beta GDP_{i,t} + \gamma\left[\partial_i(GDP)\right] + \eta pg_{i,t-k} + \sum_j \lambda_j T_j + \alpha_i + \varepsilon_{i,t}\,. \qquad (13)$$

In equation (13), the subscripts *i* and *t* denote country and year respectively. The "time" subscript (*t*) does play some role in our analysis, although we are not performing a time-series regression as we examine the relationship between taxes and aggregate income, which is represented by GDP per capita($GDP_{i,t}$). However, the model can suffer both from serial correlation in the error terms (as the gasoline taxes are correlated in time) and heteroscedasticity (as the variance of the errors may be country-specific). Since the predictions of the median voter model are derived from comparative statics, we include one lag of the dependent variable in the empirical model, as this is widely seen to provide an adequate characterisation of many dynamic adjustment processes in economics (e.g. Bun and Kiviet 2006). The presence of autocorrelation in the dataset is confirmed by applying the test developed by Wooldridge (2002)[11]. The implications of a dynamic panel for the model estimation are discussed in Section 3.4

The data are pooled for all countries, so that GDP per capita ($GDP_{i,t}$) is assumed to have the same effect on gasoline taxes in all countries, which is expected to be positive as taxes increase with aggregate income and number of drivers.

The $\partial_i(GDP)$ term determines the effect on the toll when GDP is sufficiently high that the median voter becomes a driver:

$$\begin{aligned} &\partial_i(GDP) = 1 \;\; if \;\; GDP_i \geq GDP_i^* \\ &\partial_i(GDP) = 0 \;\; otherwise \end{aligned},$$

where GDP_i^* denotes the level of GDP at which the median voter becomes a driver. GDP_i^* may differ between countries, since the same level of economic development at which the median voter becomes a driver may also depend on other country specific factors. However, the regression coefficient should be negative as, for any income level, the median voter favours a lower tax when he drives compared to when he does not. Based on a simple linearised version of the median voter model, it seems reasonable to

[11] This is implemented in STATA by xtserial.

expect that this coefficient would be the same to all countries with the same willingness to pay for road use. We therefore use one common coefficient for all countries in the dataset ($\gamma_i = \gamma$). Clearly the estimation of the GDP_i^* variable is important for the estimation of the overall model. We return to this in Section 3.3 below.

In our static theoretical model, the pre-tax price of gasoline is assumed to be fixed (parameter a in equation (1)). We therefore control for this variable ($pg_{i,t}$) in the empirical analysis as real prices do not remain constant. A lagged response is expected as governments are not able to implement policy immediately in response to price changes. In the static model, the tax would be expected to have a negative response to pre-tax price at fixed income, consistent with Goel and Nelson (1999 and Besley and Rosen (1998). In our case, we again distinguish between the two regimes when the median voter prefers to drive or not to drive. Following Proposition 3, if he is not a driver, a revenue maximiser would indeed react to a price increase of fuel by absorbing part of the price increase and decrease the gasoline tax. Also if the median voter is already a driver, the consumers' price is a mixture of the monopoly tax setting and of regulating congestion and the response to a fuel price increase would be to decrease the tax, as in Proposition 4. However, in our international panel dataset, the observed gasoline tax contains both excise and VAT for all countries except for the US[12], so that in the linear regression the derivative of tax with respect to pre-tax price also contains a VAT component. We do not attempt to correct for this as the VAT rate is a policy variable and is not fixed forever, it can increase or decrease just as can the excise. There has been some harmonization within the EU but this holds as well for excise taxes: the main reason is fuel tourism.

Clearly the pre-tax price of gasoline is influenced by major exogenous events. These are taken account of in our analysis by time dummies (T_j). Dummies are included for the following years: 1980 and 1991 (US price controls); 1990 (Gulf War); 1998 (OPEC 10% quota increase); 1999 (OPEC production cuts); and 2001 (9/11)[13].

[12] For the US, we did not distinguish the different components, as according to the IEA data source: "US Sales of motor fuels to non-commercial users are generally exempt of the general sales tax because in all states and in some municipalities' special motor fuel taxes exist. However in about eight states both taxes are cumulated. The estimates of national weighted average rates and amounts below take account of this situation as far as possible. In addition to the above a special federal motor fuel tax exists."

[13] Source: WTRG Economics: http://www.wtrg.com/

Another political consideration, not covered by the median voter theory, but which may influence gasoline taxes is the timing of elections. Governments may reduce taxes in an election year. However, including time dummies for election years is unlikely to yield any useful insights as there are elections in some country in every year of our sample period and these effects are likely to be obscured by other events[14].

Other country specific, time invariant effects are included in α_i. Given the large number of countries used in the analysis, we expect that there will be a number of factors that we cannot control for in the regression. These country specific fixed effects represent all other determinants that remain constant within a country such as the structure of political institutions, density, country size, other taxes on vehicle ownership and use etc. We assume that these are fixed effects rather than random effects as they represent omitted variables and as the panel comprises a relatively large sample of democratic countries with established gasoline tax policies. This is confirmed using a Hausmann test.

The theory outlined in Section 2 is partial in the sense that only a limited number of variables are included, which are considered to be the main determinants of the model and allow us to maintain the assumptions of the Downsian framework. In the empirical

[14] This was confirmed by regressions including one time dummy for each year.

analysis, we also mainly restrict ourselves to these major explanatory variables and prefer to incorporate others into the fixed effects. There are therefore a number of variables that, in contrast to the literature, are not included in our model, among others gasoline consumption, tax revenue and government expenditure, both as a share of GDP. In the median voter model, the number of road users, which would translate into gasoline consumption in the empirical analysis, is determined by the median voter's preferences, given the tax rule, income level, pre-tax price and road capacity. We would therefore expect gasoline consumption to be highly correlated with GDP per capita and price.[15] Government expenditure (E) appears in our theoretical model but does not play a role in the median voter's preferences as the government's budget is balanced by changes in income tax only.

3.3. Determining when the median voter drives

Finding GDP_i^*, the level of *GDP* at which the median voter becomes a driver, is central to the model estimation and should ideally be determined endogenously by comparing

[15] Indeed Hsing (1994) finds that, for US data, gasoline consumption varies positively with GDP and negatively with pre-tax price and gasoline tax.

equations (5) and (7).[16] In practice, estimating GDP_i^* endogenously would require the introduction of a relatively large number of additional variables, increasing the potential sources of error in the model. The $\partial_i(GDP)$ term is effectively equivalent to modelling a structural break in the country specific fixed effects. When the timing of a structural break is known, a Chow test can be used to test whether the coefficients estimated by the econometric model are the same before and after the break (e.g. Greene 2008). In the time series literature, tests have been developed to detect endogenous breakpoints in both constant and slope terms (Bai and Perron 1998, Andrews 1993). In a panel data setting, Mohn and Misund (2009) determine the structural change in their model endogenously by finding the break year which maximises the Chow test for the slope coefficients of the independent variables. Obfsgård and Zahran (2008) apply the Bai-Perron algorithm to search for shifts in corruption using time series data for 126 countries. Both Andrews and Lu (2001) and de Wachter and Tzavalis (2004) consider structural breaks in dynamic linear panel data models using GMM estimation techniques. The latter find that the standard Arellano-Bond estimator is robust to uncorrelated changes in fixed effects. However, the above approaches all assume that any structural breaks occur at a common point in time for all panels.

[16] In a fuller analysis, where both tax and transport investment decisions are made simultaneously, the simultaneity affects the regressions via the GDP level at which the median voter drives. Assuming a fixed capacity level, however, does not qualitatively

In our model, the break in the fixed effects may occur at different levels of GDP (and different times) for each country, as noted above: a maximisation approach is therefore difficult to apply. The shift in gasoline tax is also predicted by the theory and not the result of exogenous events. We therefore choose to specify the breakpoint before estimating the econometric model and use sensitivity analysis to take account of the accuracy of the GDP* calculation on the modelling results. As a starting point, we consider the evolution in observed gasoline price and tax rates with respect to GDP per capita (see Figures in Appendix 1). Although it is possible to identify a drop in tax rate at a real GDP per capita of roughly 18000 US dollars in year 2000 prices for a number of European countries, this is by no means clear cut. For Hungary, the Czech Republic, Poland and Slovakia, the tax seems to follow the pre-tax price trend quite closely. For these we assume that the median voter is not yet driving.

Japan, NZ, Australia, Canada and the US are the low tax regimes. Tax rates for these countries seem to grow independently of the pre-tax price. In these cases we suppose that the median voter is already driving before 1978. For NZ, Australia and Canada congestion is probably not a problem on a national scale, although congestion is undoubtedly present in large conurbations.

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affect the tax regression results.

A second approach is to use an independent dataset on car ownership data to determine the GDP level at which the median becomes a driver. In this case, annual vehicle fleet data (source IEA) and annual population data (source OECD) for each country were used to determine the year when more than half the voting adults were car owners. Data were available for1970 to 2007 with some gaps. The population data were adjusted for family size (source OECD family database and EEA) and the number of voting adults per household[17]. It was further assumed that passenger vehicles account for a fixed percentage (80%) overall fleet (these last data are not country or year specific). A simple division then yields the number of vehicles per voting adult in each year and the year in which the median voter became a car owner. The corresponding GDP then had to be inferred from the year using OECD data. Some latitude had to therefore be allowed, as real GDP does not necessarily increase monotonically over time for all countries.

The resulting GDP* values are shown in Table 1. It can be seen that, when the car ownership dataset is used, fourteen countries have already reached median voter status by 1978 and two countries have not reached it by 2006. We could therefore expect a downward shift in GDP to occur within the data period examined for twelve countries.

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[17] A fixed value of 1.5 was assumed

Since this method of calculating GDP*, although exogenous, involves some assumptions about parameter values, it is supplemented by sensitivity analysis. In the results section we also consider the effect on the regression results of the median voter becoming a car owner one year earlier or one year later than the year indicated in Table 1.

Country	Year median voter drives†	GDP* (car ownership‡)	Country	Year median voter drives†	GDP* (car ownership‡)
Australia	<1970	<20000	South Korea	1995	16000
Austria	1978	16000	Luxembourg	1976	21000
Belgium	1973	16000	Mexico	-	18000
Canada	<1970	<20000	Netherlands	1979	16000
Czech Rep.	>2006	>18000	New Zealand	<1972	<20000
Denmark	1980	22000	Norway	1973	21000
Finland	1984	20500	Poland	1999	11000
France	1973	21000	Portugal	1986	18000
Germany	1978	14000	Slovakia	2002	11000
Greece	1992	18000	Spain	1983	18000
Hungary	>2006	>13000	Sweden	1976	24000
Ireland	1976	17000	Switzerland	1979	21000
Italy	1972	18000	UK	1980	19000
Japan	1978	10500	USA	<1970	<20000

Table 1: Estimated GDP* in real US dollars at year 2000 prices

†Own calculation. ‡Corresponding real GDP then obtained from OECD Factbook data.

3.4. Estimation strategy

As is well known from the literature, ordinary least squares regression with fixed effects (which we will refer to as LSDV (Least Squares Dummy Variable) in line with the literature) is an inconsistent estimator for dynamic panel data models for finite T. Bun and Kiviet (2003) show that the leading term, $O(N^0T^{-1})$ accounts for most of the bias in the LSDV estimator and develop a bias corrected estimator (LSDVBC)[18]. When N is relatively small, as is the case in our study (N=28 and T=28), the uncorrected LSDV estimator compares well to other Generalised Method of Moments (GMM) estimators (Bun and Kiviet, 2006, Judson and Owen 1999), although the LSDVBC estimator is generally preferred, The presence of cross-sectional heterogeneity does not affect the particular form of the inconsistency of the LSDV estimator (Philips and Sul, 2007, Bun and Carree, 2006). In applied studies with similar small panels, where results are reported for both LSDV and GMM estimators (see, for example, Bruno et al 2004, Jochimsen and Nuscheler, 2005, Pock, 2007), the LSDV estimators perform reasonably well. Since the number of countries is small relative to the number of regressors[19], we

[18] This estimator was implemented in STATA by Bruno (2005).

[19] Indeed the Arellano-Bond and GMM-SYS estimators would not be appropriate for our problem as, according to Bun and Kiviet 2006, they require that N>=K(T-1) for K regressors

report results for the LSDV and LSDVC estimators only. Robust standard errors are used.

We compare two formulations of the basic regression equation (13):

a common coefficient (γ) is estimated for $\partial_i(GDP)$ and country specific fixed effects are included (α_i)

time dummies $T_j, j = 1 to 6$ are added to regression (A) for years 1979, 1980, 1990, 1998, 1999, 2001

While it would be interesting, based on our theoretical predictions, to consider a structural change in the trend variables, particularly pre-tax price, doing so highlights the main drawback of our dataset. As can be seen from Table 1, even for the countries, for which the median voter becomes a car owner during the sample period, this often happens close to the start of the sample. Hence, although this means there are a reasonable number of datapoints for estimating dGDP, there are fewer for estimating GDP and pre-tax price when the median voter prefers not to drive.

3.5. *Results*

The results for the inconsistent LSDV regression and the bias corrected LSDV estimator are presented in Table 2. The results are qualitatively comparable, with, as expected, the uncorrected estimator mainly showing a downward bias in the predictions and smaller standard errors. Two lags of the price variable were sufficient to eliminate any residual autocorrelation. Additional lags were also not found to be significant.

variable	Regression A LSDV	Regression A LSDV bias corrected	Regression B LSDV	Regression B LSDV bias corrected
$\tau_{i,t-1}$	0.8354 (0.016)***	0.8673 (0.0171)***	0.8360 (0.016)***	0.8691 (0.017)***
$GDP_{i,t}$	1.01E-06 (5.03E-07)**	7.24E-07 (4.11E-07)*	1.13E-06 (5.12E-07)**	8.53E-07 (3.93E-07)**
$pg_{i,t-1}$	-0.0650 (0.0261)**	-0.0632 (0.0256)**	-0.0538 (0.0325)*	-0.0547 (0.0313)*
$pg_{i,t-2}$	0.0463 (0.0254)*	0.0389 (0.0264)	0.0324 (0.0306)	0.0260 (0.0322)
$\partial_i(GDP)$	-0.0260 (0.008)***	-0.0237 (0.0088)***	-0.0268 (0.0080)***	-0.0244 (0.0087)**
Adj. R^2	0.9731		0.9733	
no of obs	583	583	583	583

Table 2 Regression results

(*** significant at 1% level, ** significant at 5% level, *significant at 10% level)

The regression indicates that gasoline taxes increase with increasing income and the result is found to be statistically significant at the 10% level. Based on average values, this corresponds to an approximate long run elasticity of 0.29. A simple calculation, of the long-run response of gasoline tax to pre-tax price, in which the coefficients of the lagged pre-tax price variables are simply added, shows that a unit increase in pre-tax price leads to an approximate 20% reduction in gasoline tax. The decrease in magnitude in the gasoline tax when the median voter becomes a driver, as measured by the dummy variable dGDP, is also roughly 20%. Moreover, the response to this variable is statistically significant at the 1% level.

	Median voter drives one year earlier		Median voter drives one year later	
variable	Regression A LSDV	Regression A LSDV bias corrected	Regression A LSDV	Regression A LSDV bias corrected
$\tau_{i,t-1}$	0.8375 (0.0161)***	0.8696 (0.0167)***	0.8425 (0.0159)***	0.8747 (0.0166)***
$GDP_{i,t}$	7.87E-07 (5.07E-07)	5.06E-07 (4.15E-07)	6.05E-07 (5.05E-07)	3.42E-07 (4.10E-07)
$pg_{i,t-1}$	-0.0683 (0.0262)***	-0.0662 (0.0258)***	-0.0687 (0.0263)***	-0.0665 (0.0257)***
$pg_{i,t-2}$	0.0461 (0.0255)*	0.0386 (0.0264)	0.0441 (0.0256)*	0.0363 (0.0263)
$\partial_i(GDP)$	-0.0163 (0.0076)**	-0.0145 (0.0088)	-0.0098 (0.0073)	-0.0090 (0.0089)
Adj. R^2	0.9728		0.9726	
no of obs	583	583	583	583

Table 3 Sensitivity analysis assuming median voter becomes a driver one year earlier and one year later, respectively, than calculated from car ownership data

When the median voter becomes a car owner one year earlier, there are fewer data available for estimating $\partial_i(GDP)$ and, although the sign and order of magnitude of the estimated coefficients do not change, the coefficients of GDP and $\partial_i(GDP)$ are no longer significantly different from zero. This also holds for the median voter becoming a car owner one year later. In this case, the magnitude of the downward shift may be underestimated compared to Table 2.

4. CONCLUSIONS

We have proposed a model to explain the evolution of gasoline taxes at the country level. The theory is tested on a panel dataset of 28 countries. The results indicate that, given the limitations of the data available, as predicted by the model, there is some evidence of a downward shift in gasoline tax, when the median voter becomes a driver.

There are clearly a number of simplifications and limitations in the analysis, in particular the exogenous selection of the aggregate income level at which the median voter becomes a driver in each country and the lack of data prior to the median voter becoming a driver for a number of countries. It would be interesting to repeat the analysis for data over a longer time period, at least for a subset of countries for which data exist. A second extension considered is to test the theory on a more complete cross section and to include road capacity decisions.

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APPENDIX 1

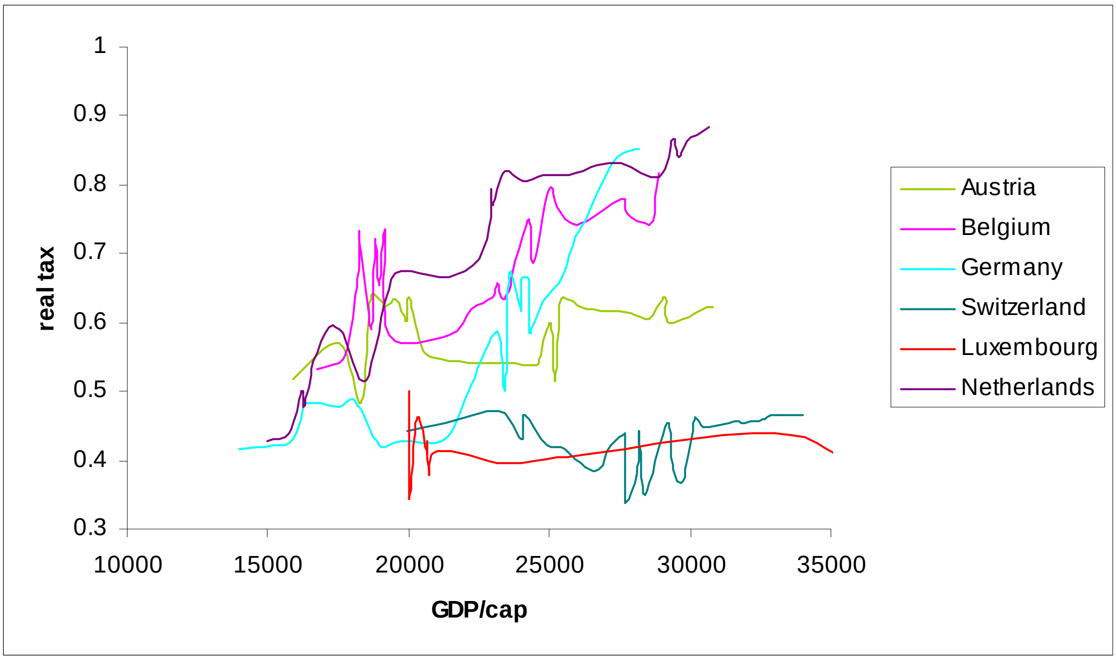

Figure A1 Observed real gasoline taxes versus GDP per capita for selected European countries (US dollars in year 2000 prices)

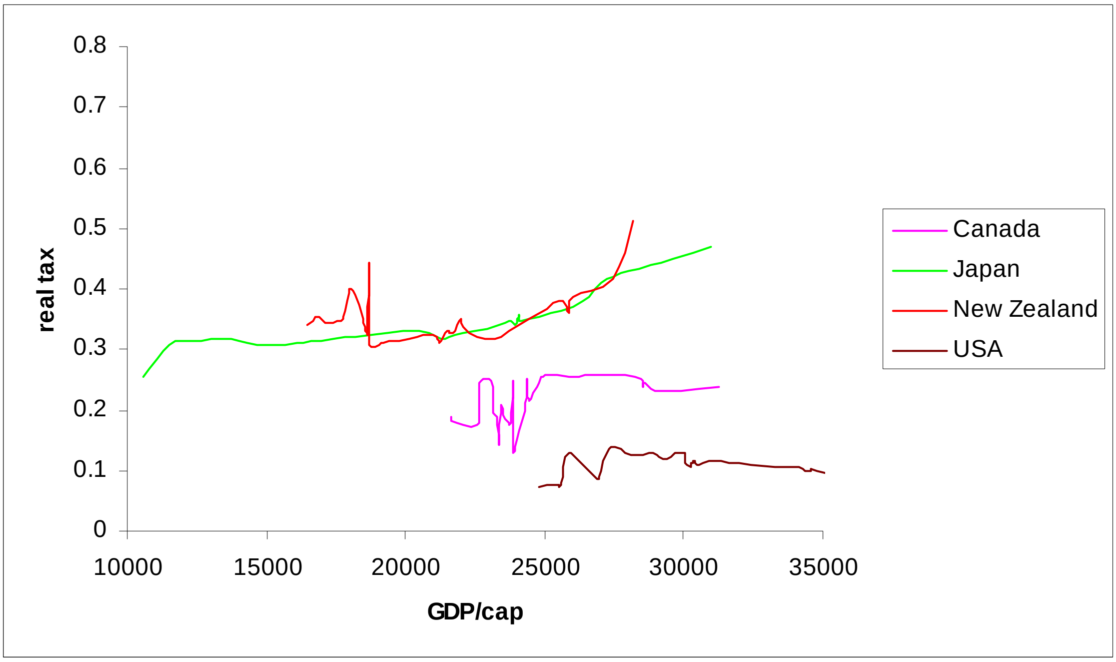

Figure A2 Observed real gasoline taxes versus GDP per capita for low tax regime countries (US dollars in year 2000 prices)

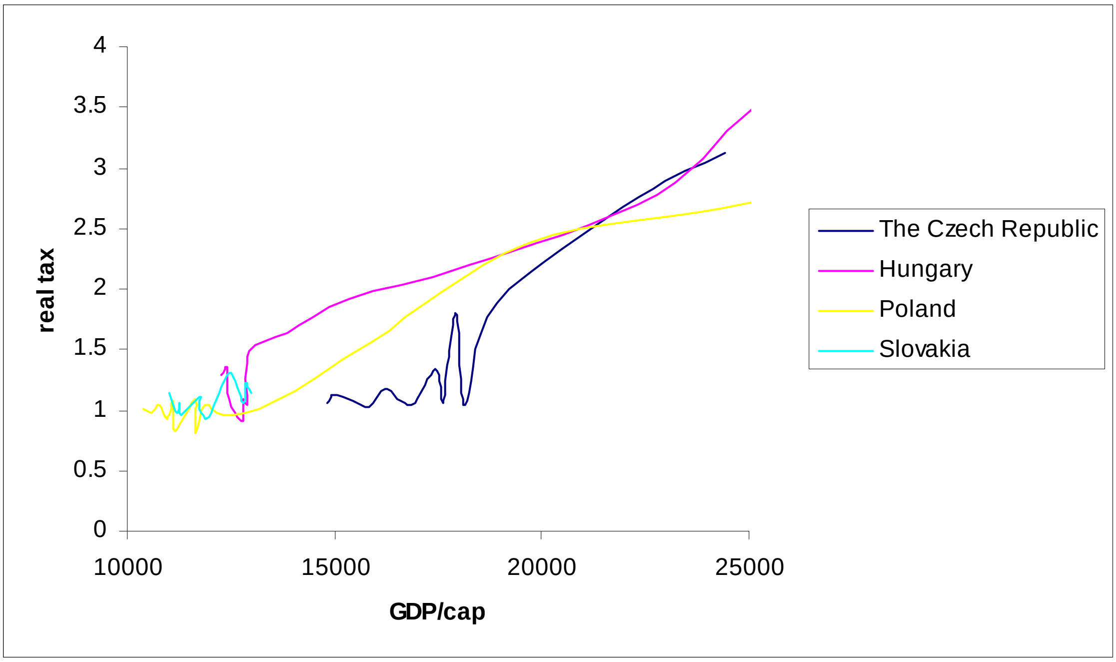

Figure A3 Observed real gasoline taxes versus GDP per capita for new member European countries (US dollars in year 2000 pr