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Road transport fuel prices, demand and tax revenues: impact of fuel duty escalator and price stabiliser

Roger Salmons

Policy Studies Institute

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Roger Salmons is a Senior Research Fellow in the Environment Group at Policy Studies Institute.

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www.greenfiscalcommission.org.uk.

Policy Studies Institute
50 Hanson Street
London
W1W 6UP

020 7911 7500

www.psi.org.uk

Green Alliance
36 Buckingham Palace Road
London
SW1W 0RE

020 7233 7433

www.green-alliance.org.uk

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Contents

Introduction ... 2
1 Trends in road transport fuel prices, demand and taxes ... 3
1.1 Fuel prices ... 3
1.2 Fuel demand ... 4
1.3 Fuel taxes ... 5
2 Impact of fuel duty escalator removal ... 7
3 Fuel price stabiliser ... 10
3.1 Decomposition of crude oil price ... 10
3.2 Design of price stabiliser ... 11
3.3 Revenue implications ... 13
3.4 Practical considerations ... 14
4 Conclusions ... 16
References ... 18
Annex A Relationship between crude oil price and retail price of petrol ... 19
Annex B Long run trend for crude oil price ... 23
Annex C Calculating fuel demand under assumption of continued duty escalator ... 26
Annex D Design of fuel price stabiliser ... 27

Introduction

Taxes on road transport fuels are an important source of revenue for the government. In 2009-10, fuel duty (and the associated VAT) amounted to £29 billion, around 6% of total revenue. However, fuel duty rates – particularly increases in rates – are an emotive topic that generates strong feelings on the part of both industry and the public.

Rapidly rising petrol prices during the second half of the 1990s under the fuel duty escalator led to increasing anger, culminating in the so-called "fuel protests" by lorry drivers and farmers in the autumn of 2000 (although the withdrawal of the escalator had been announced in November of the previous year). Duty rates – which were reduced slightly in response to the protests – then remained almost constant in nominal terms over the next seven years, before starting to rise again in 2007-8. More recently, there have been calls for a fuel price stabiliser to cushion the impact of fluctuations in the price of crude oil. The idea – which was included in the Conservative Part manifesto at the 2010 general election and was subject to a Conservative Party consultation document in 2008 (*Conservative Party*, 2008) – is currently being investigated by the Treasury.

The aim of this briefing note is to provide some objective analysis to inform the debate regarding fuel duty. In particular, the objectives of the note are:

- assess what the outcomes would have been over the period 2000 – 2010 if the fuel duty escalator had not been withdrawn in 1999, in terms of duty rates, petrol prices, petrol consumption, CO_2 emissions, and tax revenues;
- design a revenue-neutral fuel price stabiliser that can substantially reduce the short term volatility in petrol prices, while preserving the relationship between petrol prices and the long run trend in crude oil prices.

The note comprises three sections. Section one provides a brief review of the trends in road transport fuel prices, demand and taxes over the past twenty years. This is followed in section two by the assessment of the impact of the fuel duty escalator removal. Finally, section three describes a potential fuel duty stabiliser and considers some of the practical implementation issues.

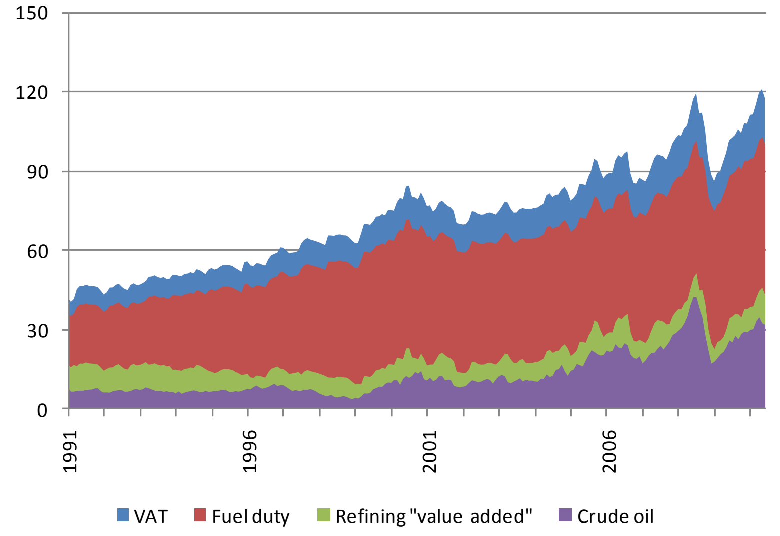
1 Trends in road transport fuel prices, demand and taxes

1.1 Fuel prices

The retail price of motor fuels has risen steadily over the last twenty years. However, there has been considerable volatility around the long run trend, particularly in later years. For example, while the retail price of premium unleaded petrol increased from just under 40 pence per litre at the start of 1991 to almost 120 pence per litre in June 2010 (see Figure 1.1) – a real increase of 83%, there were significant decreases during 2000/01 and in the second half of 2008. During the 1990s, the rise in the price was driven by increases in fuel duty (see section 1.3). Over the past ten years, the rise has been driven by the increases in the price of crude oil.

Fuel duty and VAT account for the majority of the retail price – growing from 60% of the total price for premium unleaded petrol in 1991 to a peak of 86% in March 1999 (when the fuel duty escalator was discontinued), before falling back to around 60% by the beginning of 2010.

Figure 1.1 Decomposition of retail price of premium unleaded petrol (pence per litre)[1]



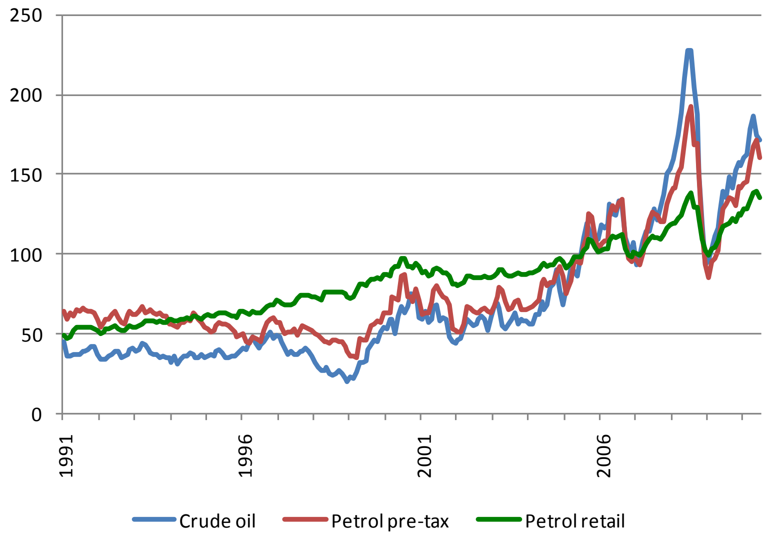
Sources: *Quarterly Energy Prices: June 2010* (DECC)
OECD Factbook 2010: Economic, Environmental and Social Statistics (for crude oil import price)

While there is a clear relationship between the price of crude oil (in sterling) and the retail price of petrol, it is highly damped (see Figure 1.2). Over recent years, the short run elasticity of the pre-tax price of petrol with respect to the crude oil price has averaged around 0.6 (see Annex A). That is, a 10% increase in the price of crude oil causes the price of petrol leaving the refineries to rise by

[1] The crude oil component of the retail price is based on the assumption that the cost of crude oil is apportioned to the various outputs from the refining process on the basis of their respective yields. This is equivalent to assuming that one litre of petrol requires the input of one litre of crude oil. Refining “value added” includes the costs of all other refining inputs. As such, it is not the same as the usual definition of economic value added.

around 6% within one month. The impact on the retail price is much smaller, reflecting the fact that fuel duty is specified in absolute terms (i.e. in pence per litre) rather than ad valorem. This has the effect of reducing the short-run elasticity – to around 0.25 over recent years. Thus, while there has been variability in the retail price of petrol around its long-term (upward) trend, it is much less volatile than the price of crude oil.

Figure 1.2 Relationship between crude oil price[(a)] and petrol prices[(b)] (index 2005 = 100)



(a) Average sterling price on a cif basis for supplies received by UK refineries from both indigenous and imported sources.

(b) Premium unleaded petrol

Source: *Quarterly Energy Prices: June 2010* (DECC)

1.2 Fuel demand

The total demand for motor fuels (i.e. petrol plus diesel) remained relatively flat from the start of 1999 to the third quarter of 2007, at around 12 billion litres per quarter, with the negative impact of the price increases over the period being offset by the growth in economic activity.[2] Since the third quarter of 2007 however, there has been a significant decline in demand, with a 10% reduction in retail sales and an 18% reduction in commercial sales.[3]

While the breakdown of demand between retail and commercial sales has remained relatively stable over the entire period, there has been a significant shift in the mix of retail sales from petrol to diesel, with the latter's share growing from 22% in 1991 to 43% by 2010.

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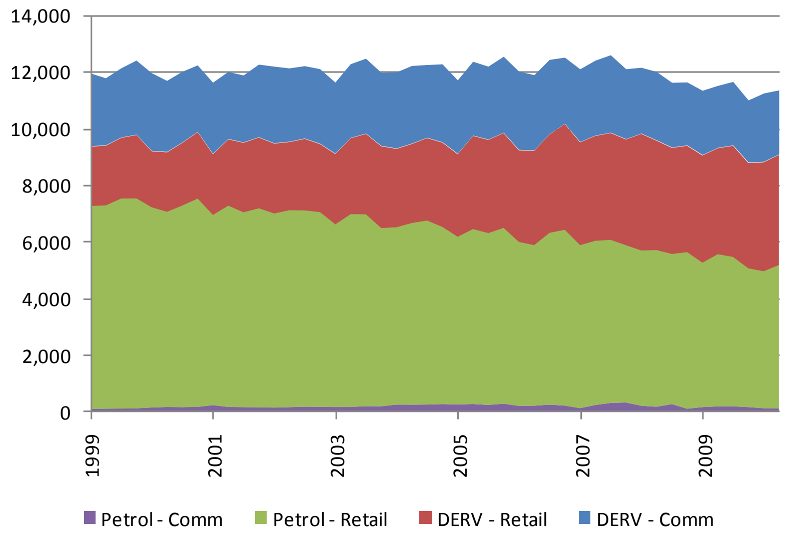
2 Between Q1 1999 and Q3 2007, the sales weighted average price of motor fuels increased by 27% in real terms. Over the same period, economic activity (as measured by the volume index for GDP) grew by 26%.

3 Retail sales are those deliveries made to petrol stations, etc., mainly for resale to final consumers. Commercial sales are those deliveries made direct to a consumer for use in their own business, e.g. to bus and coach depots.

Figure 1.3 Demand for motor transport fuels (million litres per quarter)

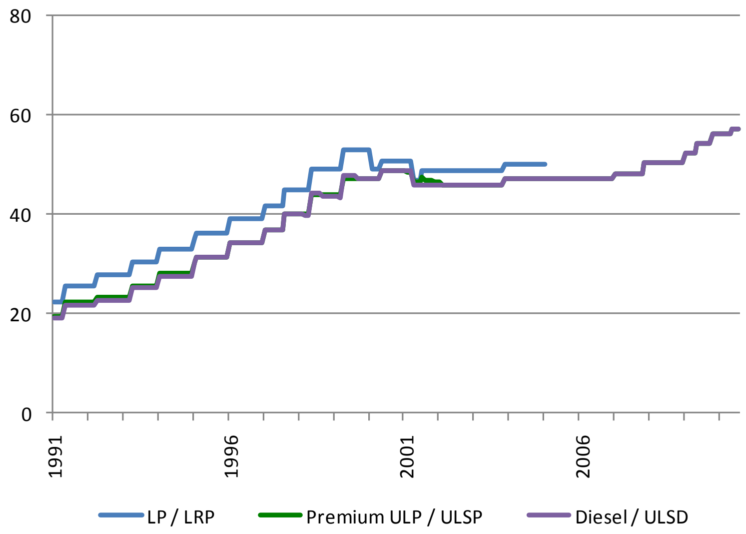


Source: Table 3.5, *Energy Trends: September 2010* (DECC)

1.3 Fuel taxes

Fuel duty rates increased significantly between 1991 and 2000 (see Figure 1.4) – due largely to the fuel duty escalator, which was introduced in 1993 and was used to determine increases in fuel duty rates until 1999.[4] Following the withdrawal of the escalator, duty rates remained relatively flat (in nominal terms) until the end of 2007, when they started to rise again.

Figure 1.4 Duty rates (pence per litre)



Source: *Hydrocarbon Oils: Historic Duty Rates* (HMRC)

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4 The fuel duty escalator was announced in the March 1993 Budget Statement and was first applied at the end of November 1993. It was last applied in March 1999 and was formally withdrawn in the November 1999 Pre-Budget Statement.

Under the escalator, increases in duty rates were required to exceed inflation (as measured by the increase in the Retail Price Index); initially by at least 3%, then by at least 5% (from November 1994), and finally by 6% (from March 1998).

Table 1.1 Fuel duty rates 1991 – 2000: premium unleaded petrol

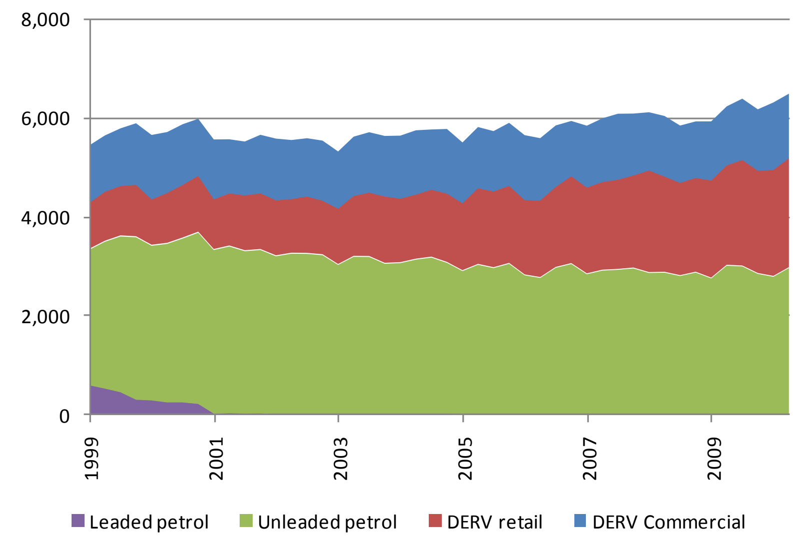
Date of change	New rate (p/l)	% change	Basis for increase	
Mar 1991	22.41	15.0%	No stated basis	
Mar 1992	23.42	4.5%	Increase RPI (Dec 1991)	
Mar 1993	25.76	10.0%	No stated basis	
Nov 1993	28.32	9.9%	At least RPI (Sep 1993) + 3%	Fuel Duty Escalator
Nov 1994	30.44	7.5%	At least RPI (Sep 1994) + 5%	
Jan 1995	31.32	2.9%	Ad hoc	
Nov 1995	34.30	9.5%	At least RPI (Sep 1995) + 5%	
Nov 1996	38.86	7.5%	At least RPI (Sep 1996) + 5%	
Jul 1997	40.28	9.3%	At least RPI + 5%	
Mar 1998	43.99	9.2%	Expected RPI (Sep 1998) + 6%	
Mar 1999	47.21	7.3%	Expected RPI (Sep 1999) + 6%	
Mar 2000	48.82	3.4%	Expected RPI (Sep 2000)	

Source: *House of Commons* (2000)

The revenue raised by fuel duty remained relatively stable from the start of 1999 to the end of 2006, at just under £6 billion per quarter (see Figure 1.5). Including the VAT levied on the duty, annual revenues averaged around £27 billion over this period; with the large majority (i.e. around 80%) being raised from retail sales.

Since 2007 there has been a slight increase in revenues, as the increase in duty rates has been partially offset by the reduction in demand. For the year ended Q2 2010, revenue totalled £29.5 billion (including VAT).

Figure 1.5 Road transport fuel duty revenue (£ million per quarter)



Source: Calculation (based on fuel demand and duty rate data)

2 Impact of fuel duty escalator removal

In this section, we consider what the outcomes would have been over the period 2000 – 2010 if the fuel duty escalator had not been withdrawn in 1999. Three alternative scenarios for the escalator are assessed:

a) RPI + 3%

b) RPI + 5%

c) RPI + 6%

In each case, it is assumed the duty rates are revised in March of each year (starting in March 2000) and are based on the (actual) increase in RPI for the following September.[5] In keeping with the actual duty rates, it is assumed that the separate (higher) duty rate for super unleaded petrol was abolished in March 2001, and that thereafter, there was a common duty rate for unleaded petrol and diesel.[6]

Figure 2.1 shows the impact of continuing the escalator on fuel duty rates. Under the 3% escalator, the duty rate rises to 88 pence per litre by June 2010, while it rises to almost 120 pence per litre under the 6% escalator. These rates compare with an actual rate for that month of 57 pence per litre.

Figure 2.1 Impact on fuel duty rate: unleaded petrol and diesel (pence per litre)

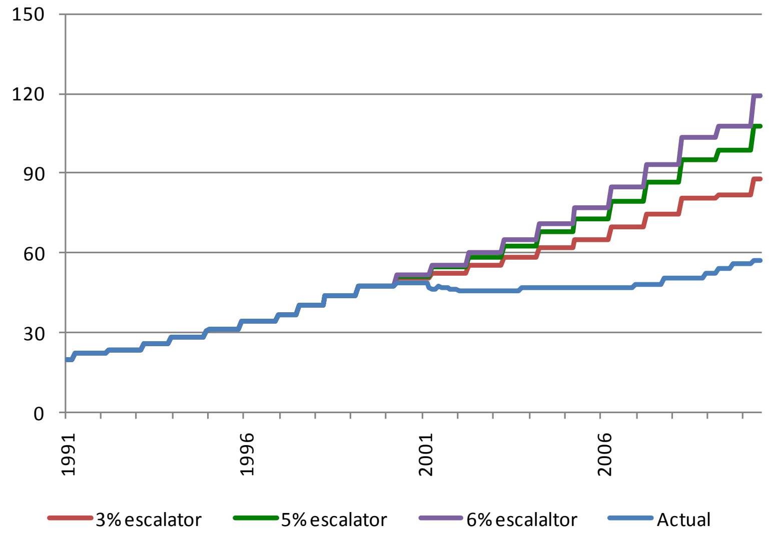


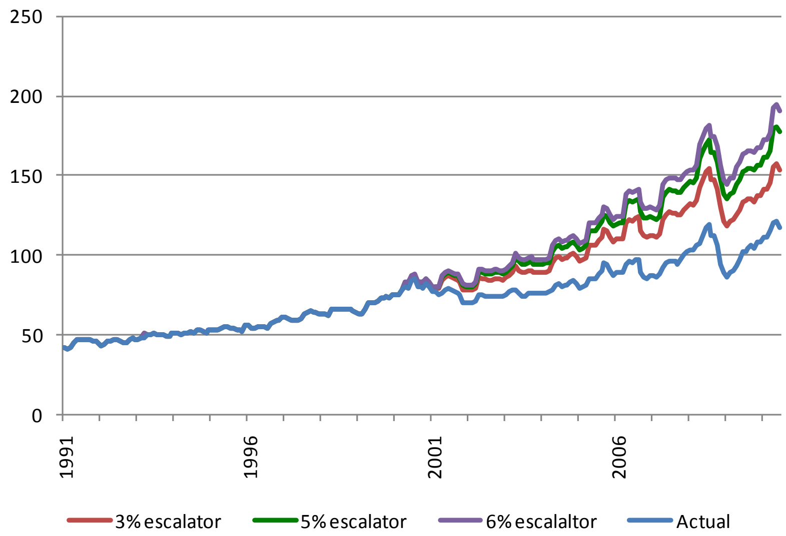
Figure 2.2 shows the resultant impact on the retail price of premium unleaded petrol, assuming that both the pre-tax price and the prevailing rate of VAT are unaffected by the continuation of the

5 This is consistent with the way in which the escalator was calculated in its final two years, when the increase was based on the expected increase in RPI for the following September.

6 As with the actual rates, the duty differential for lead replacement petrol (LRP) is maintained until the end of 2004.

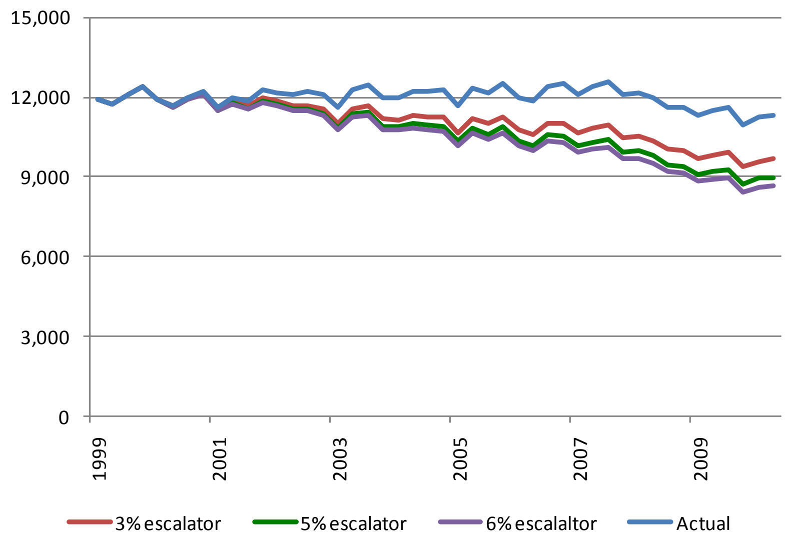
escalator. The retail price rises to 154 pence per litre by June 2010 under the 3% escalator, compared with the actual price in that month of 117 pence per litre. Under the 6% escalator, the retail price rises to 191 pence per litre (i.e. 63% higher).

Figure 2.2 Impact on retail price of premium unleaded petrol (pence per litre)



The higher retail prices have a significant impact on the demand for road transport fuels (see Figure 2.3), with total demand declining to around 8.6 billion litres per quarter by Q2 2010 under the 6% escalator, almost 25% lower than the actual figure.[7] Under the 3% escalator, demand falls to around 9.7 billion litres per quarter (almost 15% less than the actual level).

Figure 2.3 Impact on total demand for road transport fuels (million litres per quarter)



[7] The impact on demand is calculated using the average price elasticities provided by *Goodwin et al* (2004) – i.e. a short-term elasticity of -0.25 and a long-term elasticity of -0.64. Details of the calculation methodology are provided in Annex C.

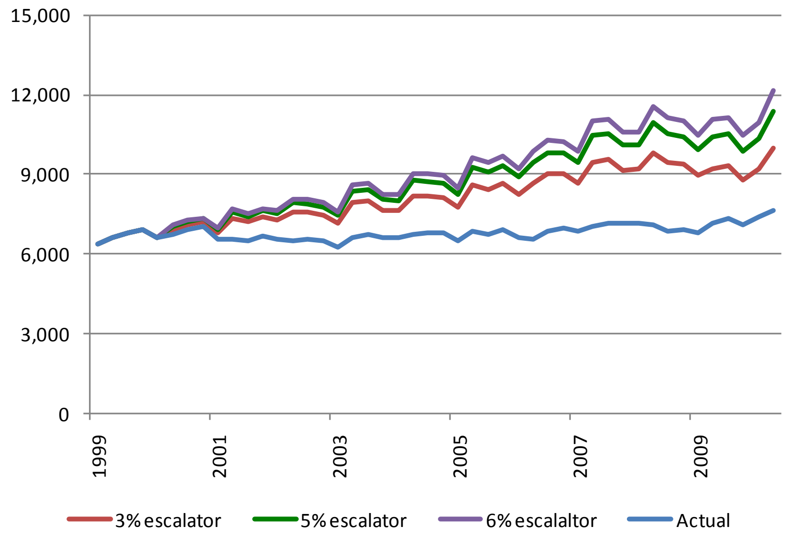
The reduction in demand is reflected in a corresponding reduction in CO_2 emissions from road transport (see Table 2.1). By Q2 2010, cumulative emissions of CO_2 are 103 million tonnes lower under the 3% escalator and 156 million lower under the 6% escalator; while annual emissions by the end of the period are 16 million tonnes lower and 26 million tonnes lower respectively. The latter figure would have represented a 5.4% decrease in total UK emissions, all else being equal.[8]

Table 2.1 Reduction in CO_2 emissions versus actual (million tonnes CO_2)

Escalator	Cumulative to Q2 2010	Year ending Q2 2010
RPI + 3%	103	16
RPI + 5%	139	23
RPI + 6%	156	26

The revenue raised by fuel duty and the associated VAT increases to around £10 billion per quarter by Q2 2010 under the 3% escalator, and to around £12 billion under the 6% escalator, compared to the actual figure of £7.6 billion (see Figure 2.4). Cumulatively, revenues would have been £61 billion higher than the actual figure under the 3% escalator and around £100 billion higher under the 6% escalator. The additional annual revenue under the 6% escalator by the end of the period – at £15.2 billion – would have been sufficient to fund a reduction in employers' national insurance contributions of around 25%, or a reduction in household income tax of around 10%.[9, 10]

Figure 2.4 Impact on duty and tax revenues (£ million per quarter)



8 The provisional estimate of UK total CO_2 emissions for 2009 is 481 million tonnes. Source: *DECC Statistical Release, 25 March 2010*.

9 Employers' compulsory national insurance contributions were £54.6 billion in 2009 (£57.1 billion in 2008), while household income taxes were £138.0 billion (£150.3 billion in 2008). Source: *United Kingdom National Accounts "The Blue Book", 2010 edition*.

10 The ability of fuel duty to replace revenues from other taxes has been noted by the Green Fiscal Commission in its Briefing Paper One (*Green Fiscal Commission*, 2009).

3 Fuel price stabiliser

While the relationship is highly damped (see section 1.1), fluctuations in the crude oil price do feed through to the retail prices of motor fuels. This can cause very sharp short-term increases in retail prices – particularly when combined with rises in fuel duty rates. In this section, we consider the design of a "price stabiliser" that would substantially reduce the short-run volatility in the retail price of petrol, while preserving the relationship between the price and the long run trend in crude oil prices.

3.1 Decomposition of crude oil price

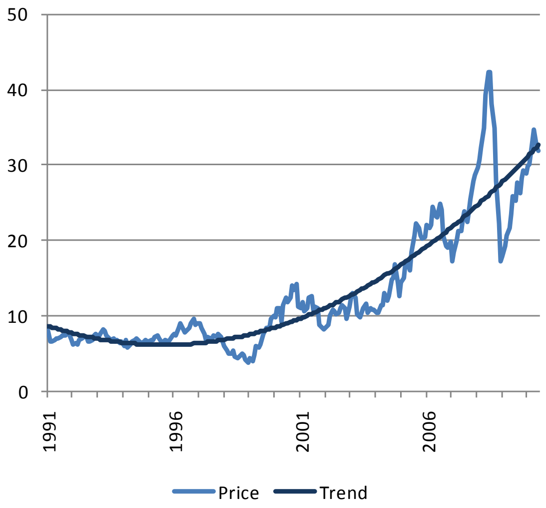
The crude oil price in any month can be decomposed into two additive components: the long term trend price and a short term deviation from the trend (see Annex B). Between 1991 and 2010, there was a four-fold increase in the long term trend price, with virtually all of the growth occurring over the last ten years (see Figure 3.1a).

There is substantial variation around the long term trend price – with deviations (in both directions) of up to 60% (see Figure 3.1b). The actual price was particularly high (i.e. deviation from the trend greater than +20%) in 1996, 2000/1, 2005/6 and 2007/8. It was particularly low (i.e. deviation more negative than -20%) in 1998/9 and 2008/9. The deviations are characterised by positive serial correlation, with alternating "runs" of successive positive and negative values – averaging around sixteen months duration.

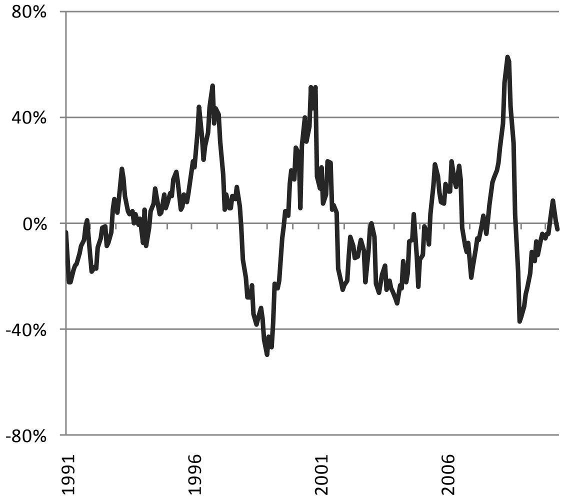
The average value of the absolute deviation around the trend line (i.e. in pence per litre) over the period 1991-2010 is zero by definition, while the average value of the percentage deviation is close to zero (i.e. +0.6%).[11]

Figure 3.1 Crude oil price

a) Long-run trend (pence per litre)



b) Deviation from trend (%)



Source: Quarterly Energy Prices: June 2010 (DECC)

[11] See Annex B for explanation of why it is not equal to zero.

3.2 Design of price stabiliser

The pre-tax price of petrol in any month (i.e. p_t) can be decomposed into four additive components (see Annex D):

$$p_t = A_t + B_t + C_t + D_t \qquad \text{... (1)}$$

where

A_t is a constant that declines over time

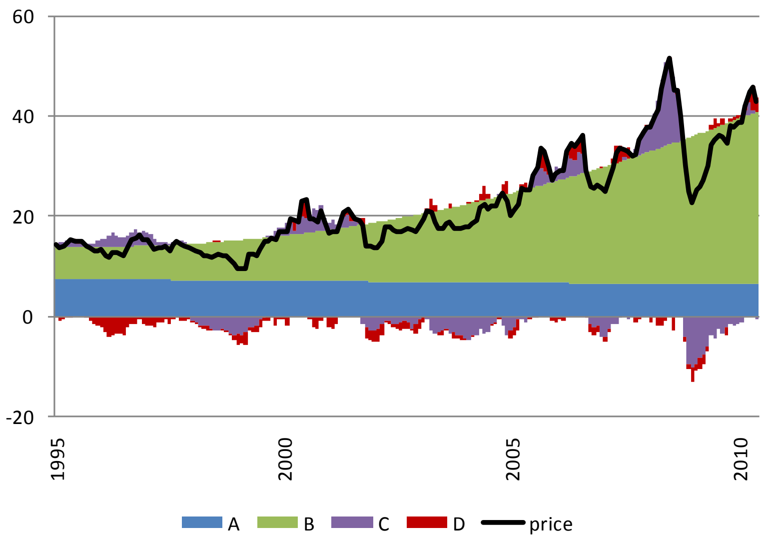
B_t represents the impact of the long term trend price of crude oil

C_t represents the impact of the short term deviations in the crude oil price

D_t represents the impact of other unidentified factors

The first two components are always positive. Together, they are equal to the long term trend price for that period. The other two components may be positive or negative, with their combined value representing the deviation from the trend price. For example, Figure 3.2 shows the decomposition of the pre-tax price of premium unleaded petrol over the period 1995 to 2010.

Figure 3.2 Decomposition of the pre-tax price of premium unleaded petrol (pence per litre)



The objective of the price stabiliser (s_t) is to remove the impact of the short term deviations in the crude oil price (C_t), while preserving the long term trend price (and other unidentified factors). That is:

$$p_t + s_t = A_t + B_t + D_t \qquad \text{... (2)}$$

Combining (1) and (2) gives the following expression for the price stabiliser:

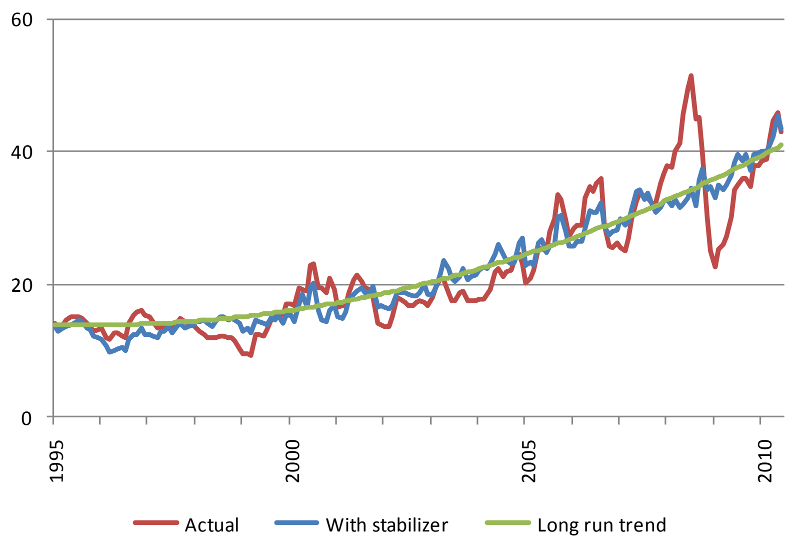
$$s_t = -C_t \qquad \text{... (3)}$$

The stabiliser is positive (i.e. equivalent to a tax) when the (smoothed) deviation from the long term crude oil trend price is negative (i.e. $C_t < 0$). It is negative (i.e. equivalent to a subsidy) when the deviation is positive (i.e. $C_t > 0$).

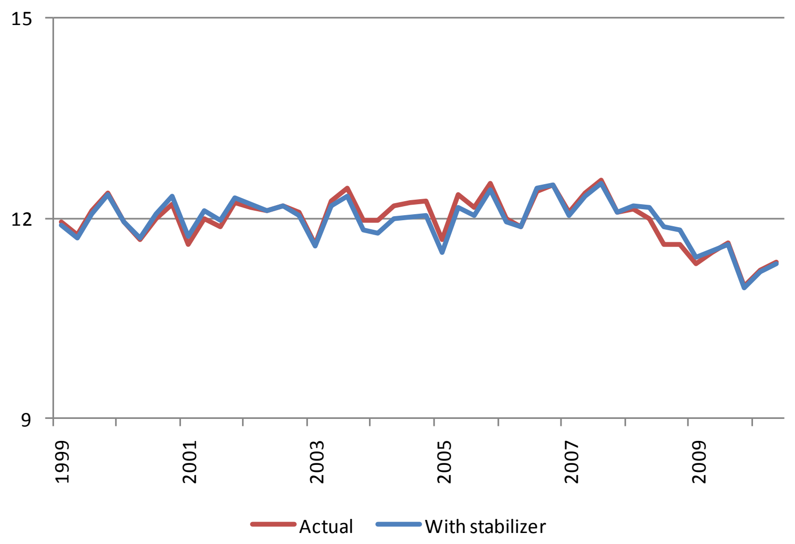
Figure 3.3 shows the impact of the stabiliser on the pre-tax price of petrol and on the total demand for road transport fuels. While the introduction of the stabiliser significantly reduces the volatility of the pre-tax petrol price, it does not eliminate it entirely due to the impact of the other unidentified factors. The stabiliser has minimal impact on demand due the sluggishness of the response to price changes (see Annex C).

Figure 3.3 Impact of stabiliser

a) pre-tax price of premium unleaded petrol (pence per litre)



b) total demand for road transport fuels (billion litres per quarter)

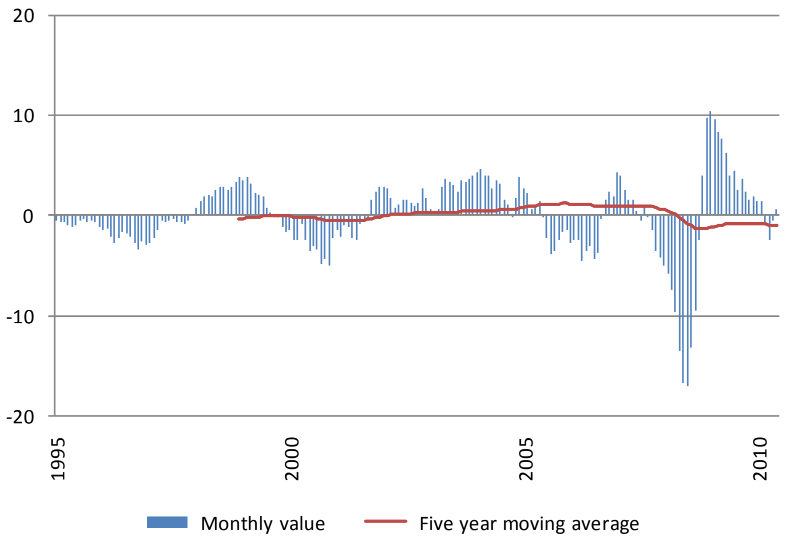


3.3 Revenue implications

Figure 3.4 shows the magnitude of the fuel stabiliser (in pence per litre) since 1994, calculated retrospectively using actual (known) fuel prices. Also shown is the five-year moving average value of the stabiliser from the year 1999 onwards.

In general, the value of the stabiliser lies between plus and minus five pence per litre. The exception to this was in 2008-9, when the value of the stabiliser declined to minus seventeen pence per litre in July 2008 following the doubling of the crude oil price over the previous twelve months, before increasing to plus ten pence in January 2009 as the oil price collapsed in the second half of 2008.[12] The five-year moving average value was close to zero between 1999 and 2004. It then rose to around plus one pence per litre by the end of 2007 before falling rapidly to around minus one and a half pence per litre by the end of 2008.

Figure 3.4 Retrospective fuel duty stabiliser for premium unleaded petrol (pence per litre)



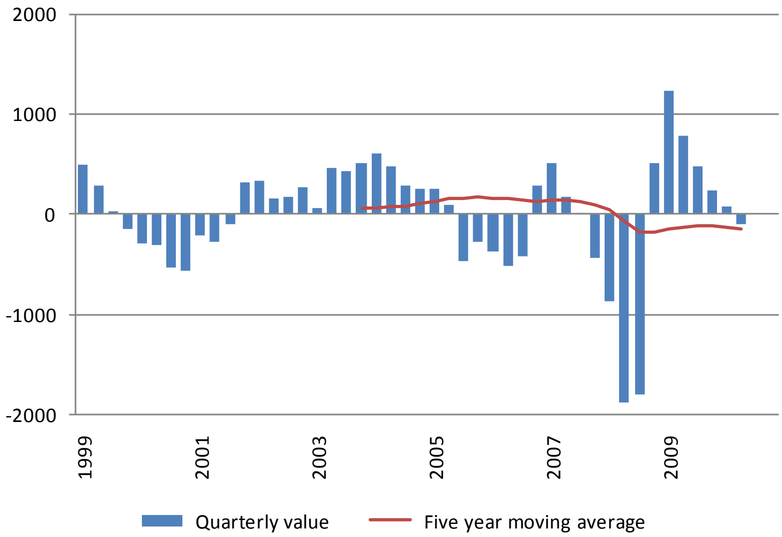
The impact of the stabiliser on tax revenues depends on the demand for fuel in each period as well as the stabiliser values. However, as was shown in Figure 1.3, the total demand for road transport fuels remained relatively flat up to 2008, before declining by around 8% over the next two and a half years. Consequently, the impact on tax revenues follows a very similar pattern to that of the stabiliser. Figure 3.5 shows the total impact on tax revenue (i.e. fuel duty and VAT) from 1999 onwards, assuming the stabiliser value is the same for all fuel types (i.e. that calculated for premium unleaded petrol), together with the five-year moving average from 2004 onwards.

Prior to 2008, the revenue impact fluctuated between plus and minus £500 million per quarter. In 2008 and 2009 the impacts were much greater, reflecting the increased magnitudes of the stabiliser in those years. However, in terms of the impacts over tax-years (i.e. April – March) the picture is more even, varying between a maximum of plus £2 billion in 2003-4 to a minimum of minus £2

[12] The crude oil price increased from 22.8 pence per litre in June 2007 to 42.3 pence per litre in June 2008, before collapsing to 17.2 pence per litre in December 2008.

billion in 2008-9. The five year moving average value fluctuated between plus and minus £180 million per quarter (i.e. less than 3% of the actual duty and associated VAT revenue collected).

Figure 3.5 Impact of retrospective stabiliser on tax revenues (£ million per quarter)



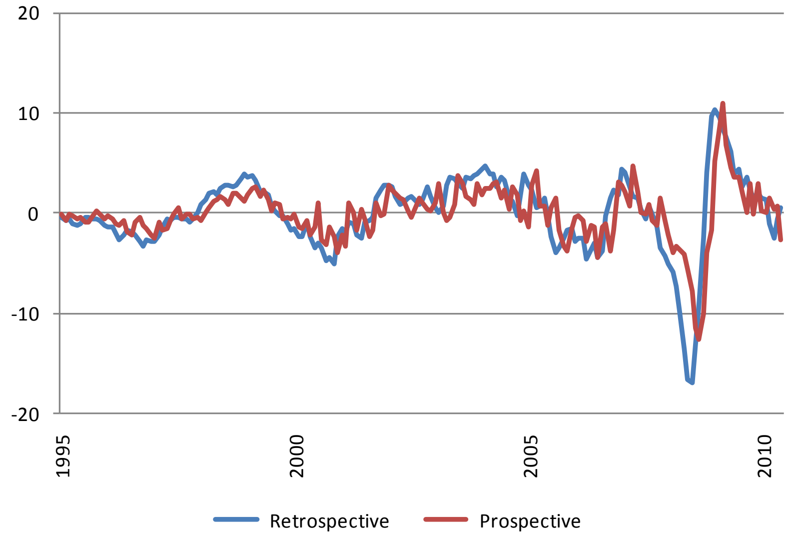
3.4 Practical considerations

The stabiliser defined by equation (3) – and shown in Figure 3.4 – requires knowledge of the deviations from the trend crude oil price in all periods – including the period to which it applies. As such, it can only be calculated retrospectively when the actual prices are available. In practice, the value of the stabiliser for any period must be set in advance, before the deviations for the latest periods are known.

Given the delay in obtaining price data and the lead-times required for implementation, it is likely that the latest available data will be three months old. For example, assuming that the stabiliser for March would have to be set in early February, the latest available data would relate to December. Consequently, it is necessary to forecast the values of the deviations for the last three months. Fortunately, the serial correlation of the deviations allows this to be done with a reasonable degree of accuracy (see Annex D) and these forecasts can then be used – with the actual values for the preceding months – to calculate a "prospective stabiliser" value.

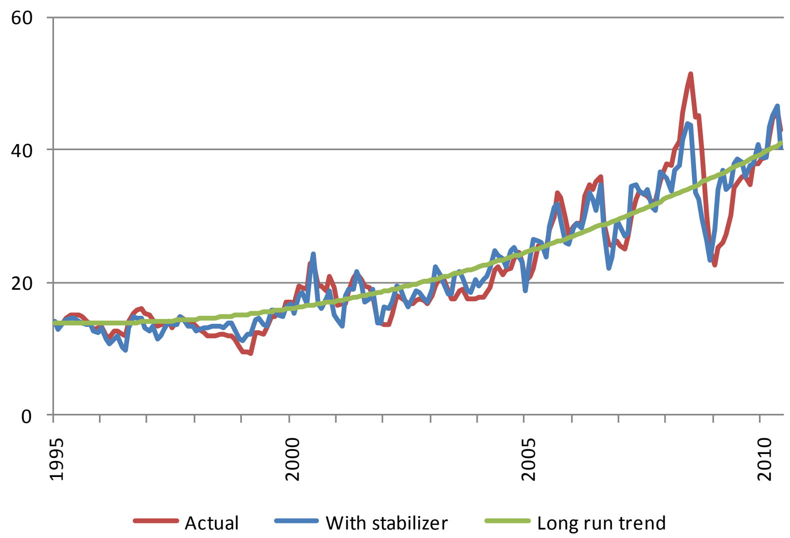
Figure 3.6 compares the prospective stabiliser values with the retrospective values. There is a reasonably strong relationship between the two values for the majority of the period – with the correlation between the two time series being 0.74. However, the prospective stabiliser has the incorrect sign in 31 of the 195 constituent months (i.e. 16%) – exacerbating the deviations in those months rather than attenuating them as intended. This was particularly significant in November and December 2008 when the prospective stabiliser failed to reflect the unprecedented decline in crude oil prices in the second half of that year. While only occurring in a small minority of cases, the potential for the prospective stabilizer to exacerbate the impacts of the oil price volatility is a serious drawback.

Figure 3.6 Comparison of retrospective and prospective stabilisers – premium unleaded petrol (pence per litre)



Despite the reasonably good fit to the retrospective stabiliser, the prospective stabiliser is much less effective at removing the volatility in the pre-tax petrol price (see Figure 3.7). It removes only 60% of the volatility due to the deviations in the crude oil price from its long term trend – compared to the 100% removal under the retrospective stabiliser (see Annex D) Furthermore, as noted above, in those months in which it has the incorrect sign, the prospective stabiliser actually exacerbates the volatility. This is particularly apparent for November – December 2008. If these two unusual months are omitted, the effectiveness of the prospective stabiliser improves to 65%.

Figure 3.7 Impact of prospective stabiliser on the pre-tax price of premium unleaded petrol (pence per litre)



4 Conclusions

The retail price of motor fuels has risen steadily over the last twenty years. During the 1990s, the rise in the price was driven by increases in fuel duty. Over the past ten years, the rise has been driven by the increases in the price of crude oil.

There is a clear upward trend in the underlying price of crude oil – with a fourfold increase over the past ten years. This trend has remained stable over time and there is no reason to expect that it will not continue in the medium term (i.e. over the next five years). However, there is considerable volatility around the long term trend price, with deviations up to 60% in either direction.

The removal of the fuel duty escalator in 1999 had a significant impact on the trajectory of petrol prices over the past ten years. If the escalator had been continued through to the present, the retail price of petrol would have been considerably higher than the current level. This would have resulted in a significant reduction in the demand for road transport fuels – and hence CO_2 emissions from road transport – and a substantial increase in the revenue raised from fuel duty and the associated VAT.

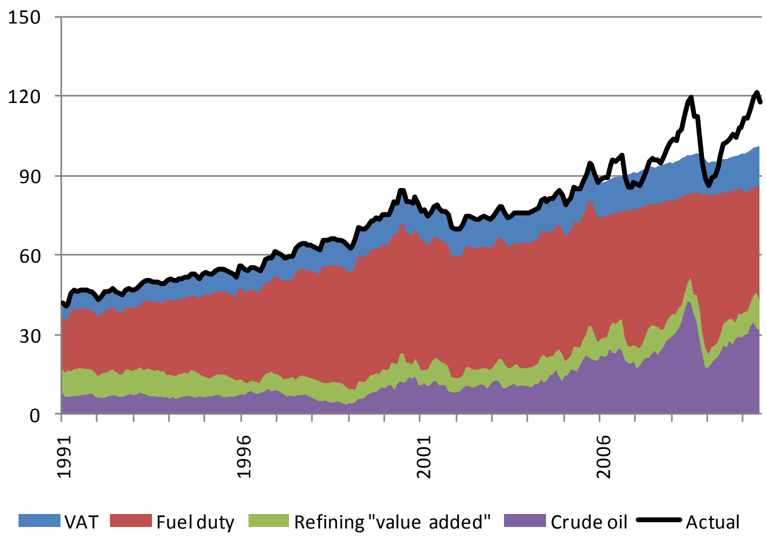
In particular, if the escalator had continued at 6% (the rate applying at the time of its removal), the retail price of premium unleaded petrol would have risen to over 190 pence per litre by the middle of 2010. Annual demand for road transport fuels would have reduced by around a quarter compared to the actual figure, while annual CO_2 emissions would have been 26 million tonnes lower, which would have represented a 5% reduction in the UK's total emissions. Furthermore, the additional duty / VAT revenue raised in 2010 – at just over £15 billion – would have been sufficient to reduce employers' national insurance contributions by around 25%, or reduce household income tax by around 10%. Alternatively, the cumulative additional revenue over the decade – at around £100 billion – would have made a major contribution to reducing the current budget deficit.

While the relationship is highly damped, fluctuations in the crude oil price do feed through to the retail price of petrol. This can cause very sharp short-term increases in retail prices – particularly when combined with rising fuel duty rates. However, it is possible to isolate the impacts of the short term deviations in the crude oil price on the pre-tax price of petrol and hence design a fuel price stabiliser that will offset them.

With perfect knowledge of crude oil prices, the stabiliser will remove all of the volatility. However, in practice, the value of the stabiliser for any period must be set in advance, before the deviations for the latest months are known. Consequently, it is necessary to forecast the deviations (and hence the crude oil prices) for these months. While it is possible it is possible to forecast these deviations with a reasonable degree of accuracy, the resultant stabiliser is only capable of removing around 60-65% of the price volatility. Furthermore, in some months, the stabiliser has the incorrect sign, exacerbating the price volatility rather than attenuating it as intended. The sensitivity of the stabiliser's effectiveness to the accuracy of the forecast deviations in crude oil prices means that the value would have to be adjusted monthly as the latest price data becomes available.

The stabilizer is broadly revenue neutral over any five-year period. However, it is important to note that this is only because it compensates for the volatility in the crude oil price around its long term upward trend. Any attempt to stabilise the price of petrol at a particular level (in either nominal or real terms) would have a significant negative impact on revenues. For example, freezing the price of petrol in real terms (i.e. increasing in line with RPI) at its December 2005 level (see Figure 4.1), would have cost the government a cumulative £8.4 billion in lower duty and VAT revenues by the middle of 2010. The cost in any particular financial year depends on the fluctuations in the oil price, but it would have been as high as £3.6 billion in 2008-9. Furthermore, the resultant increased consumption would have generated an additional 16 million tonnes of CO_2.

Figure 4.1 Decomposition of retail price of premium unleaded petrol (pence per litre) Frozen in real terms from December 2005 onwards



If the price had been fixed in nominal terms (i.e. with no increase for general inflation) then the impacts would have been significantly greater, with revenue reducing by a cumulative £23 billion by the middle of 2010 (£7.9 billion in 2008-9) and cumulative CO2 emissions increasing by 23 million tonnes.

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Annex A Relationship between crude oil price and retail price of petrol

The relationship between the pre-tax price of petrol (i.e. the ex-refinery price) at time t and the sterling price of crude oil is assumed to take the autoregressive form:

$$p_t = a + b\, q_t + c\, p_{t-1} + d\, t_t + \omega_t \qquad \ldots (1)$$

where p is the pre-tax petrol price (pence per litre)

q is the crude oil price (pence per litre)

t is a time trend variable (expressed in years)

ω represents other unidentified factors influencing price $\sim N[0,\mu]$

a, b, c, d are parameters

The lagged pre-tax price of petrol of petrol (p_{t-1}) is included as an explanatory variable to allow for the possibility that the price does not adjust immediately to changes in the crude oil price.

The <u>short-run impact</u> on the pre-tax petrol price of a change to the crude oil price is given by:

$$\frac{dp_t}{dq_t} = b$$

The <u>long-run equilibrium impact</u> (i.e. when $p_t = p_{t-1} = p$) of a step change in the crude oil price is given by:

$$\frac{dp}{dq} = \frac{b}{1 - c}$$

The parameters were estimated econometrically for premium unleaded petrol using monthly price data published in the June 2010 edition of *Quarterly Energy Prices* (DECC). As is often the case with autoregressive models, the residuals (ω) exhibit serial correlation and hence parameter estimates derived under standard OLS estimation are biased and inconsistent. Consequently, the equation was estimated using the Hatanaka two-step procedure for autoregressive models with serial correlation (see *Kennedy*, 2003). The resultant parameter estimates are shown in Table A1, along with their respective t-statistics and p-values, and the R-squared value for the transformed equation.

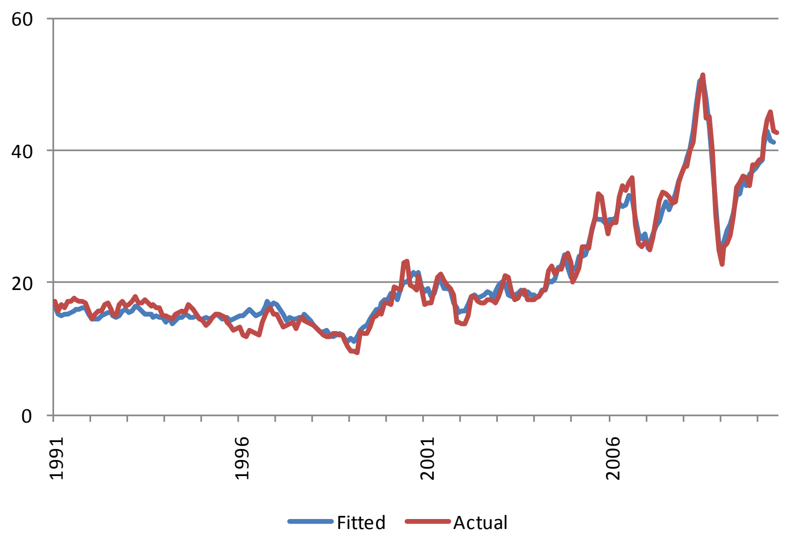
Table A1 Parameter estimates: premium unleaded petrol

Variable	Parameter	Estimate	t-statistic	p-value
Constant	a	6.358	10.30	< 0.001
Crude oil price	b	0.876	18.21	< 0.001
Lagged pre-tax petrol price	c	0.177	4.39	< 0.001
Time trend	d	-0.060	-0.85	0.40

$R^2 = 0.87$

With the exception of the time trend, all of the coefficients are highly significant and the estimated equation explains 87% of the variation in the pre-tax price of premium unleaded petrol (for the transformed model). This is reflected in Figure A1, which shows a close fit between the modelled values with the actual pre-tax prices over the period.

Figure A1 Comparison of actual and fitted pre-tax petrol prices for premium unleaded petrol (pence per litre)



The estimated short-run impact of a change to the crude oil price is 0.88 – i.e. around 90% of any increase in the price of crude oil is passed on immediately in the pre-tax price of petrol. The estimated long-run impact is 1.06 (i.e. 0.88 / (1 – 0.18). This is not significantly different from one, implying that in the long-run, any change in the price of crude oil is passed on in full.

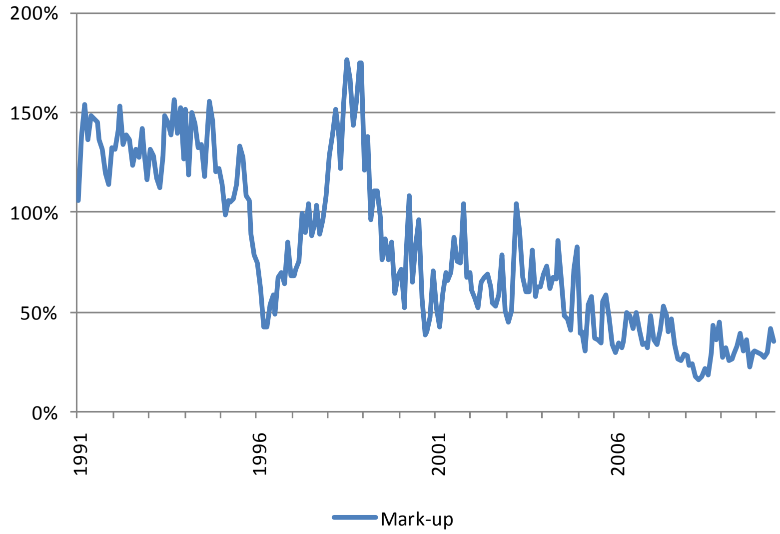
The <u>short run elasticity</u> of the pre-tax petrol price with respect to the crude oil price is:

$$\frac{dp_t}{dq_t}\,\frac{q_t}{p_t} \;=\; b\left(\frac{1}{1+m_t}\right)$$

where m_t is the percentage mark-up in period t.

Because of the linear relationship between the crude oil price and the pre-tax price of petrol (1), the mark-up varies over time. While there is considerable variation from month to month, there has been a general decline over the past twenty years (see Figure A2) with the mark-up for premium unleaded petrol falling from around 150% to around 40%. This is reflected in an increase in the short run elasticity over that period from 0.36 to 0.62.

Figure A2 Percentage mark-up: pre-tax petrol price of premium unleaded petrol versus crude oil price



The relationship between the pre-tax price and the retail price of petrol is given by:

$r_t \;=\; (1 + v_t)\,[\,p_t + d_t\,]$ ... (2)

where r is the retail petrol price (pence per litre)

p is the pre-tax petrol price (pence per litre)

v is the VAT %

d is the fuel duty rate (pence per litre)

Assuming that the fuel duty rate is set independently of the price of crude oil then the short-run and long-run impacts on the retail price of petrol of a change to the crude oil price are respectively:

$$\frac{dr_t}{dq_t} = (1 + v_t)\frac{dp_t}{dq_t} = (1 + v_t)\,b \qquad \frac{dr}{dq} = (1 + v)\left(\frac{b}{1 - c}\right)$$

Thus, the impacts on the retail price are equal to the impacts on the pre-tax price, grossed up for VAT.

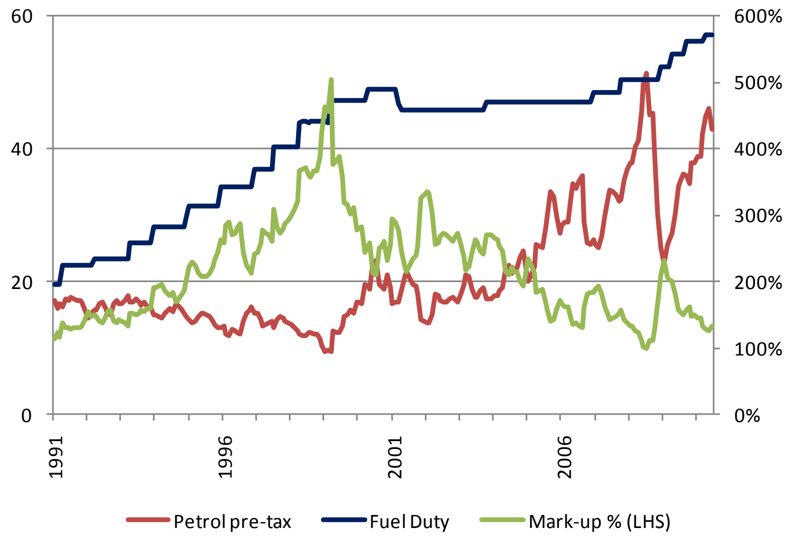
The short run elasticity of the retail price of petrol with respect to the crude oil price is:

$$\frac{dr_t}{dq_t}\frac{q_t}{r_t} = b\left(\frac{1}{1+m_t}\right)\left(\frac{1}{1+\delta_t}\right)$$

where $\delta_t = d_t / p_t$ is the value of fuel duty as a proportion of the pre-tax petrol price (i.e. the "fuel duty mark-up".

Thus, the fuel duty acts to dampen the effect of the changes in the price of crude oil. Again, the value of δ_t varies over time since the fuel duty only changes periodically while the pre-tax petrol price changes continuously (see Figure A2). Over the 1990s it increased from just over 100% to 500% as fuel duty increased under the escalator. Following the removal of the escalator, it declined sharply and has averaged around 150% in recent years. Consequently, the short run elasticity of the retail petrol price declined from 0.18 to 0.06 in 1999, before rising to its current value of 0.26.

Figure A3 Fuel duty and pre-tax petrol price (pence per litre)



Annex B Long run trend for crude oil price

The price of crude oil at time t is assumed to be given by:

$q_t = \bar{q}_t + \varepsilon_t \qquad \bar{q}_t = \alpha + \beta t + \chi t^2$ ... (3)

where

$\bar{q}$ is the long-run trend price of crude oil (pence per litre)

ε is the short-run deviation from the trend price, $\varepsilon \sim N[0,\mu]$

The parameters are estimated econometrically using monthly price data published in the June 2010 edition of *Quarterly Energy Prices* (DECC). The resultant parameter estimates are shown in Table B1, along with their respective t-statistics and p-values, and the R^2 value for the equation. While the residuals around the fitted values ($e_t = q_t - \hat{q}_t$) exhibit significant autocorrelation (see Figure B1), the estimated parameter values are unbiased and consistent.[13] Consequently, the estimated trend price values calculated using these estimates are also unbiased and consistent.

Table B1 Parameter estimates

Variable	Parameter	Estimate	t-statistic	p-value
Constant	α	8.655	13.58	< 0.001
Time in months (Jan 1991 = 0)	β	-1.101	-7.26	< 0.001
Time squared	χ	0.120	15.90	< 0.001

$R^2 = 0.85$

Figure B1 Residuals (pence per litre)

13 Autocorrelation causes the R^2 value and the t-statistics for the estimates to be overstated (and hence the p-values to be understated).

It is assumed that the autocorrelation of the residual term (i.e. the deviation) is AR(3), i.e.

$$e_t \quad = \quad \rho_1 e_{t-1} + \rho_2 e_{t-2} + \rho_3 e_{t-3} + \varpi_t \qquad \text{where } \varpi \sim N[0,\mu] \qquad \text{... (4)}$$

The values of the parameters are estimated econometrically using the residuals from the estimation of the trend equation (3). The resultant parameter estimates are shown in Table B2, along with their respective t-statistics and p-values and the R^2 value for the equation. All of the coefficients are significant and the equation explains almost 90% of the variation in the residuals.

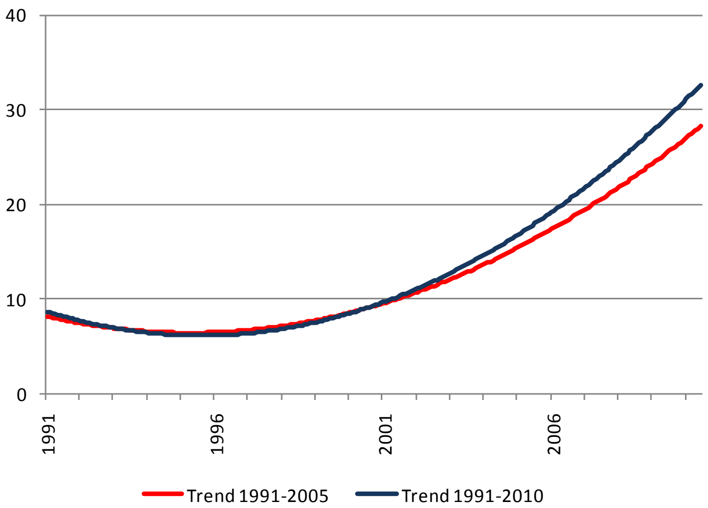
Table B1 Parameter estimates

Variable	Parameter	Estimate	t-statistic	p-value
e_{t-1}	ρ_1	1.260	19.19	< 0.001
e_{t-2}	ρ_2	-0.257	-2.45	0.015
e_{t-3}	ρ_3	-0.132	-2.00	0.047

R^2 = 0.88

The values of the parameters in the trend price equation (3) have remained relatively stable over time, with very little difference between the long term trend lines calculated using the data up to the end of 2005 and using the data up to June 2010 (see Figure B2).

Figure B2 Stability of long run trend price of crude oil



Denoting the percentage deviation from the fitted trend price ($\hat{q}_t$) by g_t then:

$$E(g_t) \quad = \quad E[\,(q_t - \hat{q}_t)/\hat{q}_t\,] \quad = \quad E(q_t/\hat{q}_t) - 1$$

Noting that the value of q_t is fixed in repeated sampling and that the inverse function is strictly convex, then by Jensen's inequality:

$$E(g_t) \quad > \quad q_t \ / \ E\,(\hat{q}_t\,) \ - \ 1 \quad = \quad q_t \ / \ q_t) \ - \ 1 \quad = \quad 0$$

Thus, the expected value of the percentage deviation at a particular point in time is greater than zero. Of course, in any particular sample, it may be positive or negative. Furthermore, the mean value across time periods is not generally equal to zero; unlike the mean value of the absolute deviation (e), which is always equal to zero by construction under OLS. .

Annex C Calculating fuel demand under assumption of continued duty escalator

The demand for fuel at time t is typically assumed to be given by:

$\ln(Q_t) = \ln(a) + b\ln(p_t) + c\ln(Y_t) + d\ln(Q_{t-1}) + \upsilon_t$ ... (5)

where Q is the total quantity of fuel consumed (million litres)

p is the real retail price of fuel (pence per litre)

Y is the level of economic activity / income (i.e. real GDP)

υ represents other unidentified factors influencing demand $\sim N[0,\mu]$

a, b, c, d are parameters

The short-run price elasticity of demand is given by the parameter b; while the long-run elasticity is given by b / (1 – d).

Denoting the actual variable values by the superscript * and the values under the continued fuel duty escalator (from time t = T) by the superscript # then, assuming that the continuation of the escalator would not have had any impact on the level of economic activity (or any other unidentified factors influencing demand), it follows that:

$Q_t^*/Q_t^{\#} = (p_t^*/p_t^{\#})^b\ (Q_{t-1}^*/Q_{t-1}^{\#})^d \qquad t = T, T+1, T+2, \ldots$ ... (6)

Consequently, the percentage impact on demand in each time period can be calculated iteratively, noting that the value of $Q_{T-1}^*/Q_{T-1}^{\#} = 1$ by definition.

The values of the parameters b and d are derived from the values provided in the review of price elasticities undertaken for the Department of Transport by *Goodwin et al* (2004). Short term and long term price elasticities for fuel consumption averaged -0.25 and -0.64 respectively (see Table C1), implying that b = -0.25 and d = 0.61 (i.e. 1 – 0.25 / 0.64). However, these values relate to annual data (i.e. the short term elasticity gives the impact after one year) and need to be converted to equivalent quarterly values as follows:

$d_Q = d^{\,0.25} = 0.884 \qquad b_Q = b\,(1 - d^{0.25}) / (1 - d) = -0.075$

Table C1 Price elasticity of fuel consumption

	Short term	Long term
Mean elasticity	- 0.25	- 0.64
Maximum	- 0.57	- 1.81
Minimum	- 0.01	- 0.00
Number of estimates	46	51

Source: *Goodwin et al* (2004)

Annex D Design of fuel price stabiliser

a) Retrospective stabiliser

Combining equations (1) and (3) and substituting the parameters with their respective estimated values gives:

$$p_t = \hat{a} + \hat{b}\,(\hat{q}_t + e_t) + \hat{c}\,p_{t-1} + \hat{d}\,t_t + w_t \quad \text{... (7)}$$

where p is the pre-tax petrol price (pence per litre)

$\hat{q}$ is the fitted long-run trend price of crude oil (pence per litre)

t is a time trend

e is the short-run deviation from the fitted trend price

w represents other unidentified factors influencing pre-tax price

$\hat{a}, \hat{b}, \hat{c}, \hat{d}$ are the estimated parameter values

But noting that $p_{t-1} = \hat{a} + \hat{b}\,(\hat{q}_{t-1} + e_t) + \hat{c}\,p_{t-2} + \hat{d}\,t_{t-1} + w_{t-1}$ ... etc., it follows that

$$p_t = (a^* + \hat{d}\,t^*_t) + \hat{b}\,\hat{q}^*_t + \hat{b}\,e^*_t + w^*_t \quad \text{... (8)}$$

where

$$a^* = [1 + c + c^2 + c^3 + \dots]\,\hat{a}$$

$$\hat{q}^*_t = \hat{q}_t + \hat{c}\,\hat{q}_{t-1} + \hat{c}^2\,\hat{q}_{t-2} + \hat{c}^3\,\hat{q}_{t-3} + \dots$$

$$t^*_t = t_t + \hat{c}\,t_{t-1} + \hat{c}^2\,t_{t-2} + \hat{c}^3\,t_{t-3} + \dots$$

$$e^*_t = e_t + \hat{c}\,e_{t-1} + \hat{c}^2\,e_{t-2} + \hat{c}^3\,e_{t-3} + \dots$$

$$w^*_t = w_t + \hat{c}\,w_{t-1} + \hat{c}^2\,w_{t-2} + \hat{c}^3\,w_{t-3} + \dots$$

Thus, the pre-tax price of petrol can be decomposed into a time-varying constant term (A_t) and three terms representing the smoothed[14] influence of:

- the long run crude oil price ($B_t = \hat{b}\,\hat{q}^*_t$)
- short term deviations in the crude oil price ($C_t = \hat{b}\,e^*_t$)
- other unidentified factors ($D_t = w^*_t$)

The estimated value of the smoothing parameter is 0.311 (see Table A1). Consequently, the weighting factors quickly fall close to zero and hence, in practice, the smoothed values can be calculated as finite summations over the last twelve months.

The influence of the short term deviations in the crude oil price can therefore be removed by introducing a stabiliser:

$$s_t = -\,\hat{b}\,e^*_t \approx -\,\hat{b}\,[e_t + \hat{c}\,e_{t-1} + \hat{c}^2\,e_{t-2} + \dots + \hat{c}^N\,e_{t-N}] \quad \text{... (9)}$$

[14] They are equal to the exponentially weighted moving averages multiplied by 1 / (1 – c).

Thus, the value of the stabiliser depends not only on the deviation from the trend price in the current period, but also the deviations in previous periods. It is positive (i.e. equivalent to a tax) when the (smoothed) deviation from the long term crude oil trend price is negative (i.e. $\varepsilon^*_t < 0$). It is negative (i.e. equivalent to a subsidy) when the deviation is positive (i.e. $\varepsilon^*_t > 0$).

Noting that E(e) = E(ε) = 0, the expected value (mean) and variance of the stabiliser are respectively:

$$E(s_t) = -\hat{b}\, E(e^*_t) = -\hat{b}\, [\, E(e_t) + \hat{c}\, E(e_{t-1}) + \hat{c}^2\, E(e_{t-2}) + \ldots + \hat{c}^N\, E(e_{t-N})\,] = 0$$

$$Var(s_t) = \hat{b}^2\, [\, \hat{\mathbf{c}}\, \mathbf{V}_e\, \hat{\mathbf{c}}'\,]$$

where $\hat{\mathbf{c}} = (\, 1, \hat{c}, \hat{c}^2, \ldots, \hat{c}^N\,)$

$$\mathbf{V}_e = \begin{bmatrix} cov(e_t,e_t) & \cdots & cov(e_t,e_{t-N}) \\ \vdots & \ddots & \vdots \\ cov(e_{t-N},e_t) & \cdots & cov(e_{t-N},e_{t-N}) \end{bmatrix}$$

Furthermore, since the component residuals are serially correlated (see Annex B), it follows that the stabiliser values are also serially correlated with the same AR(3) form – i.e.

$$\begin{aligned} s_t &= -\hat{b}\, [\, e_t + \hat{c}\, e_{t-1} + \hat{c}^2\, e_{t-2} + \ldots + \hat{c}^N\, e_{t-N}\,] \\ &= -\hat{b}\, [\, (\, \rho_1 e_{t-1} + \rho_2 e_{t-2} + \rho_3 e_{t-3} + v_t\,) + \hat{c}\, (\, \rho_1 e_{t-2} + \rho_2 e_{t-3} + \rho_3 e_{t-4} + v_{t-1}\,) \\ &\qquad + \hat{c}^2\, (\, \rho_1 e_{t-3} + \rho_2 e_{t-4} + \rho_3 e_{t-5} + v_{t-2}\,) + \ldots + \hat{c}^N\, (\, \rho_1 e_{t-N-1} + \rho_2 e_{t-N-2} + \rho_3 e_{t-N-3} + v_{t-N}\,)\,] \\ &= -\hat{b}\, [\, \rho_1\, (\, e_{t-1} + \hat{c}\, e_{t-2} + \hat{c}^2\, e_{t-3} + \ldots + \hat{c}^N\, e_{t-N-1}\,) + \rho_2\, (\, e_{t-2} + \hat{c}\, e_{t-3} + \hat{c}^2\, e_{t-4} + \ldots + \hat{c}^N\, e_{t-N-2}\,) \\ &\qquad + \rho_3\, (\, e_{t-3} + \hat{c}\, e_{t-4} + \hat{c}^2\, e_{t-5} + \ldots + \hat{c}^N\, e_{t-N-3}\,) + (\, v_t + \hat{c}\, v_{t-1} + \hat{c}^2\, v_{t-2} + \ldots + \hat{c}^N\, v_{t-N}\,)\,] \\ &= \rho_1 s_{t-1} + \rho_2 s_{t-2} + \rho_3 s_{t-3} - \hat{b}\, v^*_t \qquad \ldots (10\_ \end{aligned}$$

Thus, the stabiliser follows the same cyclical pattern as the deviations from trend crude oil price.

The M-period <u>moving average</u> value of the stabiliser is given by:

$$\tilde{s}_t = [\, e_t + e_{t-1} + e_{t-2} + \ldots + e_{t-M+1}\,] / M \qquad \ldots (11)$$

It follows directly that the expected value of the moving average is zero and the variance is given by:

$$Var(\tilde{s}_t) = [\, \mathbf{i}\, \mathbf{V}_s\, \mathbf{i}'\,] / M^2$$

where $\mathbf{i} = (\, 1, 1, 1, \ldots, 1\,)$

$$\mathbf{V}_s = \begin{bmatrix} cov(s_t,s_t) & \cdots & cov(s_t,s_{t-N}) \\ \vdots & \ddots & \vdots \\ cov(s_{t-N},s_t) & \cdots & cov(s_{t-N},s_{t-N}) \end{bmatrix}$$

Thus, the variance of the moving average is equal to the average covariance across all M×M combinations of the lagged stabiliser values. Table C1 shows the values of the variance for the stabiliser and for the moving average values over 3, 5 and 8 years – together with the average, minimum and maximum values. The variation in the moving average falls quickly as the length of the averaging period increases; with the magnitude of the five-year average fluctuating by less than three pence around zero.

Table C1 Variance of stabiliser and moving average values (pence per litre)

	Stabiliser	Moving Average		
		3 Years	5 Years	8 Years
Mean	-0.07	-0.09	0.11	0.18
Variance	13.57	1.30	0.71	0.50
Minimum	-17.02	-3.33	-1.38	-0.65
Maximum	10.40	2.41	1.19	1.06
Spread	27.42	5.74	2.57	1.71

b) Prospective stabiliser

In practice, the value of the stabiliser for any period must be set in advance, before the deviations (e) for the latest periods are known. Given the delay in obtaining price data and the lead-times required for implementation, it is likely that the latest available data will be three months old (i.e. will relate to period t-3). However, it is possible to use the use the serial correlation of the deviations (as defined by equation (4) in Annex B) to construct forecast values (made at time t-3) for the last three periods, i.e.

$$\hat{e}_{t-2} = \rho_1 e_{t-3} + \rho_2 e_{t-4} + \rho_3 e_{t-5}$$

$$\hat{e}_{t-1} = \rho_1 \hat{e}_{t-2} + \rho_2 e_{t-3} + \rho_3 e_{t-4}$$

$$\hat{e}_{t} = \rho_1 \hat{e}_{t-1} + \rho_2 \hat{e}_{t-2} + \rho_3 e_{t-3}$$

While the forecasts become successively less accurate, the final forecast (for period t) still provides a reasonably good fit to the actual deviations in most periods (see Figure D1 below) – with a correlation coefficient for the two time series of 0.70.

Using these forecast values for the deviations, a "prospective stabiliser" can be calculated as[15]:

$$\hat{s}_t = -\hat{b}\,[\,\hat{e}_t + \hat{c}\,\hat{e}_{t-1} + \hat{c}^2\,\hat{e}_{t-2} + \hat{c}^3\,e_{t-3} + \dots + \hat{c}^N\,e_{t-N}\,] \qquad \dots (12)$$

15 It is also possible to use the serial correlation of the stabiliser values (as defined by equation 10) to forecast the stabiliser values directly. However, using the forecast deviations is slightly more accurate and requires minimal additional computation.

Figure D1 **Comparison of actual deviations with forecast values made three months earlier (pence per litre)**

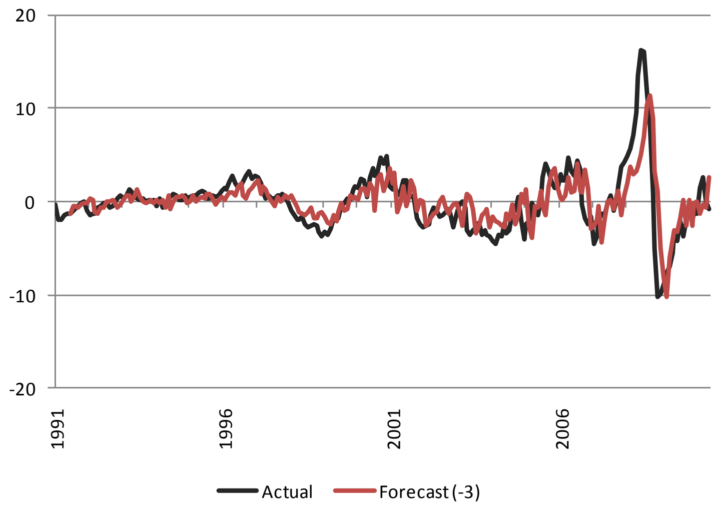
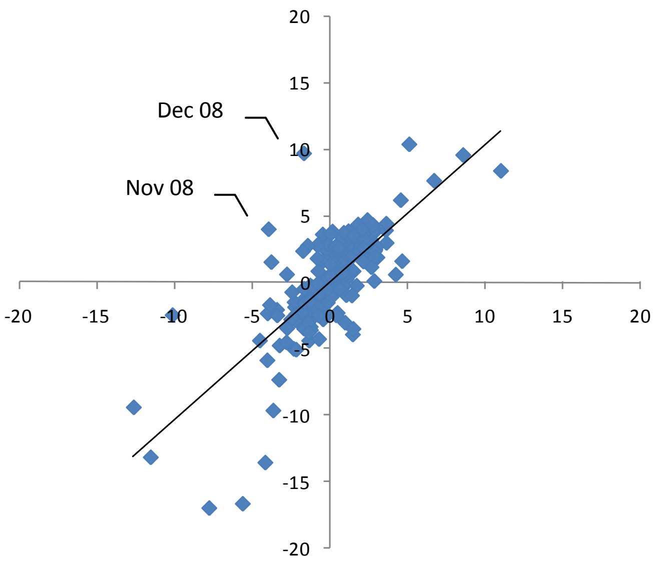


Figure D2 compares the prospective stabiliser values with the corresponding retrospective values over the period April 1994 – June 2010. There is a reasonably strong relationship between the two values for the majority of the period – the correlation between the two time series is 0.74. However, the prospective stabiliser has the incorrect sign in 31 of the 195 constituent months (i.e. 16%) – exacerbating the deviations rather than attenuating them as intended. In most cases, the magnitude of the difference was less than 2 pence (e.g. the retrospective stabilizer value is plus 1 pence rather than minus 1 pence, etc.). However, in some cases it is significant. In particular, in November and December 2008, the prospective stabiliser failed to reflect the unprecedented decline in crude oil prices (the deviation value falling from plus 16 pence in June to minus 10 pence in December) and hence remained significantly positive rather than changing sign as required.

Figure D2 **Comparison of retrospective and prospective stabiliser values (pence per litre)** [(a)]

(Correlation = 0.74)



(a) Retrospective value on vertical axis, prospective value on horizontal axis

The effectiveness of the prospective stabiliser in removing the volatility in the pre-tax petrol price due the deviations in the crude oil price from its long run trend can be measured by:

$$\sigma \ = \ 1 - \frac{\sum \left(\hat{s}_t + \hat{b}\, e_t^* \right)^2}{\sum \left(\hat{b}\, e_t^* \right)^2}$$

By definition, $\sigma = 0$ in the absence of any stabiliser, while $\sigma = 1$ for the retrospective stabiliser (since $s_t + \hat{b}\, e^*_t = 0$). For the prospective stabiliser, $\sigma = 0.6$. That is, it removes 60% of the volatility due to the fluctuations in the crude oil price.