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The impact of congestion charging on vehicle emissions in London

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Abstract

The London congestion charging scheme (CCS) was successfully implemented in February 2003 and has measurably reduced traffic flows in central London. The air pollution impact of the scheme has been difficult to assess using ambient measurements alone as the air pollution concentrations in 2003 were higher than in 2002 because of unusual meteorological conditions. However, a comprehensive analysis of the impact using detailed traffic data, combined with the Environmental Research Group's road traffic emissions model, has identified a number of important results. First, between 2002 and 2003, total NO_X emissions in the charging zone have reduced by -12.0% $\pm 12\%$ (2σ) and have increased on the inner ring road (IRR) by $+1.5\%$. PM_{10} emissions have reduced by -11.9% in the charging zone and by -1.4% on the IRR. There is a significant reduction in the emissions of NO_X and PM_{10} associated with increases in vehicle speed and that this is as important in reducing emissions as changes in vehicle numbers. There is also evidence that the speed changes in $km\,h^{-1}$ are uniform across the whole range of average speed and therefore changes at the slower speeds have a disproportionate effect on vehicle emissions. Second, that changes in vehicle km, as a result of the scheme, are large (-15% $\pm 4\%$ (2σ)) particularly in the charging zone itself. To meet the demand to travel into central London there has been increased bus use. However, the expected increase in emissions from buses have been mostly offset by the widespread introduction of particle traps to the new and existing bus fleet as well as the introduction of newer technology bus engines. Finally, there is a reduction in emissions of CO_2 (-19.5%) but that unlike NO_X and PM_{10} little additional benefit is apparent through new vehicle technology. The evidence presented shows that the congestion charging schemes could assist in attaining both the UK government's targets on air pollution as well as those relating to climate change and other international obligations.

Keywords: Environment and transport planning; Road user pricing; Climate change; Traffic emissions; Traffic congestion

1. Background

The implementation of the London Congestion Charging Scheme (CCS) began in February 2003, using a single charge of £5 for vehicles entering a central London zone between the weekday hours of 07:00–18:30. Although several vehicle types are exempt from the charge, the effect of the scheme has been to reduce the vehicle km travelled within the zone by –15% $\pm 4\%$ (2σ) and to increase the speed by an average of $4\,km\,h^{-1}$ $\pm 10\%$ (2σ) or $+20\%$. Uncertainty estimates in the speed results are given by Chooi (2004) and for vehicle km changes by Buckingham (personal communication). The CCS area is approximately $22\,km^2$ or 1.3% of the Greater London area, and contains some of the most congested

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conditions anywhere in London. The first example of a scheme of this type is in Singapore, whose Area Licensing Scheme (ALS) began operation in 1975 and required a license to gain access to a 'restricted zone' within the central city area. This system was superseded by an Electronic Road Pricing system (ERP) in 1998. The ERP now charges vehicles according to vehicle type, time of day and location, having regard to the level of congestion. Since the introduction of the scheme, road traffic flows have reduced by −20% and speed has increased by + 33% (Chin, 1996; Tuan Seik, 2000). Elsewhere the theoretical benefits of congestion pricing have also been reported. Daniel and Bekka (2000) predicted that vehicle emissions (NO_X, CO and HC) could be reduced by up to 30% in the most congested areas. Begg and Gray (2004) identified increased congestion in the UK as being a "more salient concern" than local air pollution and although many of the UK government's air pollution targets will be met through improvements in vehicle technology, some areas will not achieve the required standards. Furthermore, they reported that a reliance on technology and the lack of demand management in relation to road transport would potentially jeopardise the UK's ability to meet its climate change targets and local air pollution problems in the medium to long term. Begg and Gray (2004) also recommended that consideration be given to a national road charging scheme that would tackle both CO_2 emissions and benefit local air pollution problems at the same time. The Future of Transport white paper (DfT, 2004) used the London Congestion Charging Scheme as a real and timely example of the potential benefits of road user charging.

Analyses of the air pollution impacts of the CCS directly from measurements have proved to be difficult, because in 2003 there was an increase in concentrations of the pollutants PM_{10}, NO_2 and O_3 compared with 2002 as the result of exceptional meteorological conditions (Environmental Research Group, 2004). For 2003 it was reported that a large number of incidents of high PM_{10} concentrations occurred in February, March, April and August and were caused largely by secondary sources. During 2003 the average of all inner London background PM_{10} sites measured an additional 24 days where the daily mean PM_{10} concentration was above $50\,\mu g\,m^{-3}$, compared with 2002. In addition there was an exceptionally long photochemical season, defined in terms of the number of hourly mean concentrations of $O_3 > 100\,\mu g\,m^{-3}$. During August 2003 the highest hourly O_3 concentration in the 10 year history of the London Air Quality Network (LAQN), was measured at $260\,\mu g\,m^{-3}$. In inner and central London the annual average NO_2 concentration, calculated from all background sites combined, also increased from 45 to $50\,\mu g\,m^{-3}$ or 11%. These conditions have therefore made it difficult to detect any changes in concentration of key atmospheric pollutants.

2. Method

The CCS impacts have been estimated using a combination of extensive traffic monitoring and the emissions model used to create the road traffic emissions inventory for the London Atmospheric Emissions Inventory (GLA, 2001). Changes to the emissions of NO_X, PM_{10} and CO_2 were made by applying vehicle changes between pre-CCS (2002) and post-CCS (2003) years, for each hour of the day, weekday and weekend, separately for the inner ring road (IRR—the charging zone boundary) and the charging zone. In summary, the changes in vehicle km were calculated using manual count data taken from 282 locations, automatic count data from 70 locations and average road link speed using moving car observer (MCO) speed estimates. It should be noted that estimates of traffic volume and speed changes quoted below will differ slightly from those already published by TfL (2004), owing to necessary assumptions made in applying the TfL count and speed survey data to the specific requirements of the emissions model. Changes in vehicle stock and technology characteristics have also been applied between pre- and post-CCS years using a similar method to that of the National Atmospheric Emissions Inventory (Goodwin, 2002). However, for buses and taxis specific London vehicle stock estimates have been made because of the importance of these vehicle types in London (GLA, 2001), including in the case of buses, the number of vehicle fitted with new engines and exhaust particle traps. A complete description of the emissions modelling methodology and the London Atmospheric Emissions Inventory is available from the Greater London Authority.

3. Results

Table 1 shows the average changes in annual average daily traffic (AADT) flows for different vehicle types as a result of the CCS. The most notable changes in vehicle km in the charging zone area were an increase in buses (+ 20%), an increase in taxis (+ 13%), associated with their increased use for work journeys, and a reduction in cars (−29%) and heavy goods vehicles (−11%). On the IRR there has been a large increase in bus use (+ 25%) as well as an increase in LGVs and HGVs by 8% and 5%, respectively. Changes in other vehicle types have been small.

Tables 2 and 3 summarise the estimated change in emissions results broken down into those associated with changes in vehicle speed, change in vehicle km and through the improvement in vehicle technology between 2002 and 2003. The increase in speed associated with the CCS has created a large reduction in emissions of NO_X for both the IRR and charging zone. This benefit of

Table 1
The percentage change in vehicle km travelled for 7 vehicle types between 2002 and 2003

	Motorcycles	Taxis	Cars	Bus and coaches	LGV	Rigid	Artic
IRR	5	−2	1	25	8	5	5
Charging zone	3	13	−29	20	−11	−11	−11

Table 2
The percentage change in NO_X and PM_{10} emissions on major roads in the congestion charging zone and on the IRR

	NO_X emissions $\pm 12\%$ (2σ) (see AQEG NO_2, 2004)		PM_{10} emissions	
	IRR	Charging zone	IRR	Charging zone
CCS speed changes	−4.1	−7.9	−4.8	−8.5
CCS vehicle km changes	5.6	−4.1	−3.4	−3.4
CCS overall change	1.5	−12.0	−1.4	−11.9
Additional benefit of improved vehicle technology	−5.7	−3.9	−5.4	−4.0
Total change in emissions	−4.2	−15.9	−6.8	−15.9

Table 3
The percentage change in CO_2 emissions (based on 2002) by vehicle type and speed change brought about by the CCS

	IRR	Charging zone
Charging zone speed changes	−4.7	−9.5
Charging zone vehicle km changes	4.7	−10.0
Charging zone overall change	0.0	−19.5
Additional benefit of improved vehicle technology	−0.6	−0.4
Total change in emissions	−0.6	−19.9

increased speed counteracts the general increase in traffic on the IRR and the resulting increase is modest at +1.5%. Overall there is a reduction in NO_X emissions in the charging zone of −12%.

Although not an effect of the CCS itself, the additional benefit brought about by improvements in vehicle technology between 2002 and 2003 have the effect of reducing NO_X emissions by a further −5.7% for the IRR and −3.9% for the charging zone. This is despite the improvements in the emissions performance of cars since the introduction of the catalytic converter and is primarily the result of the combined improvements in emissions of cars, LGVs and rigid HGVs. The resulting NO_X emissions reduction is −4.2% for the IRR and −15.9% for the charging zone.

The pattern of PM_{10} emissions is similar to NO_X, with the most significant benefit being through an increase in speed. In the charging zone the benefit of increased speed outweighs both the benefit of changes in vehicle km and improvements in vehicle technology. For the charging area the reduction in emissions of PM_{10} is estimated to be −11.9%. It should be noted that the small impact of buses is due to additional vehicle km being driven by a new bus fleet with particle traps, which are highly effective at reducing PM_{10} emissions. The additional benefit of vehicle technology between 2002 and 2003 is −5.4% for IRR and −4.0% for charging zone. The resulting emissions reduction between 2002 and 2003 is −15.9% for the charging zone and –6.8% for the IRR.

The mean daily speed (in the charging zone) increased by $4\,km\,h^{-1}$ $\pm 10\%$ (2σ) from 19 to $23\,km\,h^{-1}$, between 2002 and 2003. However, a regression analysis of speed shows that no relationship exists between the change in speed and the average speed ($R^2 = 0.004$). Because speed is applied in the ERG emissions model, on a road by road basis, changes at very low speeds disproportionately affect changes in the emissions. This is most clearly seen in Figs. 1 and 2 where a plot of percentage change in NO_X and PM_{10} emissions, (on each road in central and inner London), due only to changes in average link speed produces a scatter of points with an increasing range at the lowest speed (approx. $15\,km\,h^{-1}$).

The introduction of the CCS has not only shown benefits for emissions of NO_X and PM_{10}, but also for CO_2. The results, summarised in Table 3, provide the incremental percentage changes for each of the CCS effects. Once again the increase in speed associated with the CCS has resulted in a significant reduction in emissions of CO_2 for each of the areas considered. The benefit of increased speed counteracts the small increases

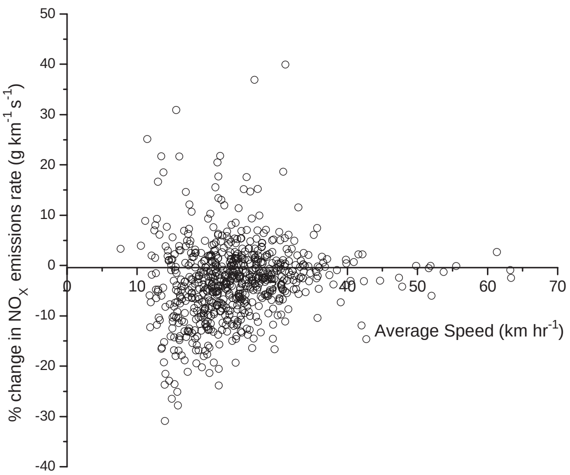

Fig. 1. The percentage change in NO_X emissions (post CCS – pre CCS) due only to changes in average link speed.

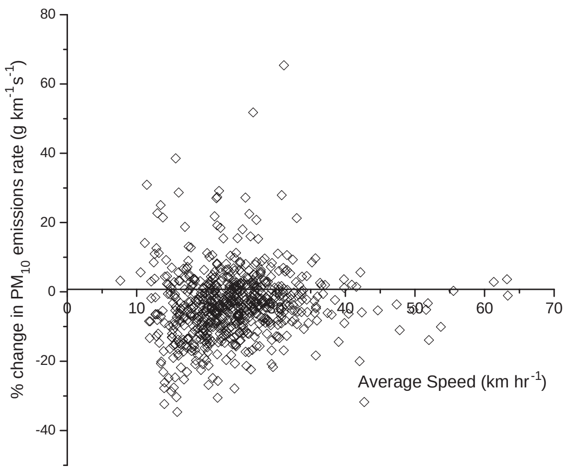

Fig. 2. The percentage change in PM_{10} emissions (post CCS – pre CCS) due only to changes in average link speed.

in traffic on the IRR and results in no change in CO_2 emissions. For the charging area the benefit of a reduction in vehicle km combines with the benefit in increased speed to give a reduction of 19.5% in emissions of CO_2. It is also worthy to note that unlike emissions of NO_X and PM_{10}, very little additional benefit is gained through the change in technology between 2002 and 2003.

4. Discussion and conclusions

Several important results are apparent from the analysis of the effect of the London congestion charging scheme. First, there is a significant effect associated with increases in vehicle speed brought about by the reduction in congestion and that the changes at slower speeds have a disproportionate effect on vehicle emissions. Second, that changes in vehicle km as a result of the scheme are large, particularly in the charging zone itself. To meet the demand to travel into central London an increase in bus vehicle km was also evident, but bus emissions have been offset to some extent because of the widespread introduction of particle traps to the new and existing bus fleet. Finally, there is a reduction in emissions of CO_2, providing evidence that a scheme of this kind will assist in attaining government targets relating to climate change, but that unlike NO_X and PM_{10} little additional benefit is apparent through introduction of new vehicle technology between 2002 and 2003.

It must be stressed that although comprehensive traffic data was used to calculate the impact associated with the introduction of the CCS and the emissions were calculated using recognised emissions inventory methods that these retain a high level of uncertainty. Additionally, there are a number of limitations in this analysis. For example, emissions of non-exhaust PM_{10}, e.g. tyre and brake wear and re-suspension have not been accounted for in the calculations and so the results presented may well underestimate the benefits of the scheme. This is because these emissions might be expected to reduce with a reduction in vehicle km. Nevertheless an increase in vehicle speed may also have the effect of increasing the resuspended fraction. Furthermore, the results presented are for major roads only and further investigation of minor road effects is required. Finally, recent work (Carslaw and Beevers, 2004a,b) has shown that large diesel vehicles and particularly those travelling at slow speeds emit a larger proportion of NO_X as NO_2 directly from their exhausts and that these effects have not been considered. The widespread fitting of particle traps to London's bus fleet may therefore be an important consideration in assessing the effect of the CCS.

Acknowledgements

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