Has the introduction of a congestion charge in central London contributed to an improvement in the city's air quality?

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Abstract

The London congestion charging scheme has been in place since the 17th of February 2003 and there is little doubt that, so far, the objectives set out prior to the introduction of the charge have been achieved. The purpose of this paper is to examine the effect the congestion charge have had on the air quality in central London. This was done by studying daily data on a number of pollutants that can be connected to vehicle emissions, both before and after the introduction of the congestion charge. The pollutants studied include nitrogen oxides (nitrogen dioxide and nitric oxide), carbon monoxide and hydrocarbons (benzene and 1,3 butadiene). The result of this study show that the levels of carbon monoxide and hydrocarbons have fallen significantly while the levels of nitrogen oxides (NO_X) appear to have risen.

Keywords: London congestion charge, air quality, pollutants

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1. Introduction

Just over one million people work in central London and of these it is estimated that one in seven travels to work by car. Prior to the congestion charge being introduced in central London, this meant that over 50 000 vehicles entered central London every hour at peak times, at an average speed of approximately 14 km/h (Dix, 2002). These vehicles then ended up spending about half of their time in stationary or slow-moving queues (Banister, 2003). These facts highlight the need for a congestion charge in the central London area.

Congestion charging, which requires each vehicle to be charged a fixed amount for crossing the cordon into the city centre (Banister, 2003), was introduced in central London on the 17th of February 2003 and the scheme currently covers the heart of central London, a congestion zone currently bound by the Inner Ring Road, although there are plans to extend the congestion zone to the west. The congestion zone is at present relatively small, covering an area of only 21 km^2. The entire greater London area covers 976 km^2 (610 square miles). This area is home to approximately 370 000 inhabitants or 5.4 per cent of the population of Greater London (Prud'Homme & Bocarejo, 2005).

Nevertheless, the London congestion charging scheme represents a dramatic step towards internalising the externalities associated with driving. As drivers generally fail to take into account the effect that their vehicle has on others, this can be referred to as a neglected externality (Shaffer & Santos, 2003). With the congestion charge in place, drivers in central London have to pay for part of the effect their vehicle has on others.

Figure 1: The London Congestion Zone

Source: http://www.bbc.co.uk/london/congestion/maps/map_main.shtml
01-01-2006

The London congestion charging scheme came into force with four main objectives to be achieved, which were presented in the Mayor's 2001 Transport Strategy. These objectives include reducing congestion in London, making radical improvements to bus services, improving journey time reliability for car users and making the distribution of goods and services more reliable, sustainable and efficient (TfL, 2003). The congestion charge may, however, also bring a potential benefit not included in these objectives. This is the potential environmental benefits that can be gained from the reduction in traffic resulting from a congestion charging scheme. Put simply, less vehicle km travelled means that fewer pollutants are produced (Prud'Homme & Bocarejo, 2005). As the charge has only been in place for just over three years and taking into account the unusual meteorological conditions that persisted in the UK during most of 2003 and which affected the air quality in a negative way, it is difficult to assess what impact, if any, the congestion charge may have had on air quality in London. Prior to the introduction of the congestion charge, the Mayor of London stated that the scheme was not likely to have any significant environmental impact (Banister, 2003). It is nevertheless interesting to see if the reduced number of vehicles in the congestion zone has had any impact on the air quality in central London.

1.1 Purpose and method

The purpose of this paper is to examine how the introduction of a congestion charge in central London has affected the city's air quality. Air pollution affects human health as well as the environment and is a major problem in the world today, particularly in major cities like London. Emissions from traffic sources are responsible for a large portion of urban air pollution. The task of examining the possible effects of a congestion charge on the city's air quality is carried out by studying data, obtained from the UK Air Quality Information Archive,[1] on a number of pollutants that can be connected to vehicle emissions and the effect these pollutants have on the air quality in central London, both before and after the introduction of the congestion charge. This is done by performing regression analysis, using daily data on a number of pollutants collected between 2001 and 2006, to see if the introduction of a congestion charge in central London has had any impact, positive or negative, on the air quality in and around the congestion zone.

1.2 Disposition

Section 2 reviews the background on the London congestion charging scheme and how it is implemented. Here, the results of the scheme (not connected to air quality issues) are presented. Section 3 looks at the relationship between air quality and pollutants emitted into the air. In particular, the pollutants studied in this paper and their effects on human health are presented. The air quality standards and objectives for the UK are presented and there is also a brief review of the statistically unusual metrological conditions that the UK experienced during 2003. Section 4 consists of a presentation of the data used and in section 5 the results are presented and analysed. In section 6, some concluding remarks are presented.

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[1] www.airquality.co.uk 9 May 2006

2. Background

Transport for London (TfL) defines congestion as the difference between the average network travel rate and the un-congested (free-flow) network travel rate in minutes per vehicle kilometre (Blake & Shaffer, 2003). As Blake & Shaffer (2003) point out, it is important to note that optimal congestion is not zero as this would indicate that the road space was being under-used. However, there is an optimal level of congestion although this level is very difficult to define. Road usage is defined as the number of four-wheel vehicle km per day in the charged zone, with buses being excluded.

The concept of congestion charging, or road pricing, in London is not a new issue. Back in the early 1960s, the Ministry of Transport appointed a panel to investigate the technical feasibility of various methods for improving the pricing system for the use of roads (Dix, 2002). This panel's findings were reported in the so-called Smeed report, where use of direct road charges was recommended.

It was not until 1999, however, when the Greater London Authority Act was passed by the British parliament, that congestion charging started on the road to becoming reality in central London. When the Greater London Authority Act was passed by the British parliament, it formed the Greater London Authority and gave London a unique political structure consisting of an elected mayor and a separately elected Assembly, which have a scrutinising role. It was the Greater London Authority Act that in effect gave the Mayor of London the powers to introduce a congestion charging scheme in London (Dix, 2002). In May 2000, Ken Livingstone was elected the first Mayor of London with a manifesto that prominently featured the congestion charge.

As mentioned above, even before the Greater London Authority Act was passed, congestion charging had been seriously looked into as an appropriate policy for London. In 1991, the Department of Transport commissioned the London Congestion Charge Research Programme and the findings were subsequently published in 1995. Following this research programme, the London Planning Advisory Committee (LPAC) recommended congestion charging as an appropriate measure for London in their 1998 Strategic Advice to the Secretary of State (Dix, 2002). In the same year, the Road Charging Options for London (ROCOL) carried out a study that would form the basis for the central London congestion charging scheme. The ROCOL study concluded that an area licensing system with a charge of £5 a day would have a significant impact on the level of traffic in London. The scheme was to be enforced using Automatic Number Plate Recognition (ANPR) technology.

Soon after Ken Livingstone was elected Mayor of London in May 2000, he began the preparations for making congestion charging in London a reality. In June 2000, the Mayor appointed Transport for London (TfL), lead by director of street management Derek Turner, the task of investigating the options for implementing a congestion charging scheme in central London. In July 2000, the process of public consultation on the planned congestion charge began. A discussion paper titled *Hearing London's Views* was sent to nearly 400 key stakeholders including the London boroughs, London MPs, business groups and transport operators (Dix, 2002). The result showed support for the proposition. The next step in the process was the publication of the Mayor's draft titled *Transport Strategy* in January 2001. This in turn generated approximately 8000 written responses, showing public stakeholders and interested parties broadly in favour of the proposed scheme. In July 2001 the *Final Transport Strategy* was published confirming the introduction of a congestion charging scheme in London. As a final part of the consultation process, TfL ran an exhibition as well as hosting two public meetings in August and September 2001. At these events, the general public got the opportunity to express their views about the proposed congestion charging scheme and a number of modifications were made. Following these modifications, the scheme was then presented to the Londoners again in January 2002 and in February the same year the Mayor made the final, definite decision to go ahead with the project.

The initial daily charge was set to £5 a day and the charge were to apply weekdays between 7am and 6.30pm, with Bank holidays being excluded. The charge has subsequently been raised to £8 a day, with the increase coming into force on the 4th of

July 2005. TfL were appointed the charging authority. According to TfL's report *Congestion charging 6 months on*, published in October 2003, the scheme was expected to generate £68 million in its first year and £80 to £100 million in future years of operation. For at least the next ten years, all proceeds from the congestion charge must be spent on improving transport in London.

2.1 Results of London's congestion charging scheme so far

In its first year of operation, the congestion charging scheme managed to reduce congestion in central London by just over 30 per cent (Shaffer & Santos, 2003). TfL's expectations of a reduction in congestion between 20 and 30 percent had thus been met. Further, overall traffic levels fell by 16 percent and the average speed increased from 14 km/h to 17 km/h, an increase of about 20 per cent (Shaffer & Santos, 2003). An increase of only 3 km/h may seem like a small improvement but it is nevertheless a step in the right direction. Six months into the scheme, drivers in the congestion zone were also spending less time in traffic queues, with time spent either stationary or travelling at below 10 km/h reduced by about a quarter (TfL, 2003). There is no doubt that, so far, the traffic reduction objectives of the charge have been reached and that the London congestion charging scheme is a success.

In early 2007, London's congestion zone will be extended to the west. This western extension was confirmed by the Mayor on the 29th of September 2005 and will become effective on the 19th of February 2007. The extended congestion zone will be bound by Harrow Road (with a number of deviations), the West Cross Route, the inner southbound arm of the Earls Court one way system and the Chelsea Embankment. This means that as of the 19th of February 2007, Notting Hill, Chelsea and Kensington, among others, will be included in the congestion charging zone.

3. Air quality and pollutants

According to the London Air Quality Network[2], an organisation managed by the Environmental Research Group (ERG) at King's College in London that works to coordinate and improve air pollution monitoring in London, air pollution is made up of a mixture of gases and particles that have been released into the atmosphere by man-made processes. A significant portion of this air pollution is produced by motor vehicles. Air pollution is hence an external cost of vehicle use, a cost depending on, according to the Victoria Transport Policy Institute[3], the vehicle itself, the type of fuel used and the conditions under which the vehicle travels. For example, urban driving imposes greater air pollution costs than does rural driving since, in urban areas, a great number of vehicles can generally be found in a relatively small area. This results in congestion which in turn contributes to poor air quality in this area. In the countryside, the roads are generally not congested and vehicle emissions are not as significant.

The London Air Quality Network states that there are seven main air pollutants. These are carbon monoxide (CO), nitrogen dioxide (NO_2), ground level ozone (O_3), particulate matter (PM10, PM2,5), sulphur dioxide (SO_2), hydrocarbons (including benzene and 1,3 butadiene) and lead. Of these seven pollutants, four are usually found near busy roads and can hence be connected to vehicle emissions. These four pollutants are carbon monoxide, nitrogen dioxide, particulate matter and hydrocarbons.

For each of the major air pollutants, Air Quality Standards have been set. The standard for each pollutant is set at a concentration, measured over a given time period, below which pollution levels are considered acceptable in the light of what is known about its effects on human health and the environment[4]. For example, as reported by the London Air Quality Network, the air quality standard for nitrogen dioxide is 150 ppb measured as a one hour mean. Further, air pollution levels are classified into bands to help the public

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2 www.londonair.org.uk/london/asp/home.asp 18 April 2004
3 www.vtpi.org 6 April 2004
4 London Air Quality Network www.londonair.org.uk/london/asp/information.asp?vie=howbad 15 May 2006

assess the possible health impacts of pollution above certain thresholds, where the first of these thresholds, the *standard* threshold, is based on the air quality standard for each pollutant. Further thresholds are the *"information*" and *"alert"* thresholds that are in line with the EC directives on Air Quality[5]. Table 1 shows the air quality bands for carbon monoxide, nitrogen dioxide and particulate matter (PM10). Any concentration below the *standard* threshold is labelled *low* air pollution while levels between the *standard* and *information* thresholds would be described as *moderate*. When the concentration of a pollutant lies between the *information* and *alert* thresholds, it is labelled *high* and any level above the *alert* threshold is defined as *very high*.

Table 1: Air Quality Standards

Description	**Low**	**Moderate**	**High**	**Very High**
CO (ppm, 8 hour running average	<10	10 - 14	15 - 19	> = 20
NO_2 (ppb, hourly average)	<150	150 - 299	300 - 399	> = 400
PM10 (µg/m^3, 24 hour running average)	<50	50 – 74	75 – 99	> = 100

Source: London Air Quality Network's *A guide to pollution*
www.londonair.org.uk/london/asp/information.asp?view=howbad 15 May 2006

As well as the air quality standards, air quality objectives for eight main pollutants have been set for the UK by the Government's Air Quality Strategy, which were developed in 1998[6]. These objectives are similar to the air quality standards but with some differences arising because the UK must comply with European Directives on air quality. In some cases, the UK-based standards have been replaced by European standards. The air quality objectives were reviewed in 1999 and continue to be reviewed at regular intervals. The National Air Quality Strategy's air quality objectives for the pollutants studied in this

[5] London Air Quality Network www.londonair.org.uk/london/asp/information.asp?view=howbad 15 May 2006
[6] http://www.londonair.org.uk/london/asp/information.asp?view=howbad 15 May 2006

paper (excluding NO) are presented in table 2. The objectives for nitrogen dioxide are provisional.

Table 2: Air Quality Objectives

Pollutant	**Air Quality Objective**
Benzene	5 ppb measured as running annual mean
1,3 Butadiene	1 ppb measured as running annual mean
Nitrogen dioxide (NO_2) (i)	105 ppb not to be exceeded more than 18 times a year, measured as a 1 hour mean
Nitrogen dioxide (NO_2) (ii)	21 ppb measured as annual mean
Carbon monoxide (CO)	10 ppm measured as running 8 hour mean

Source: London Air Quality Network's *A guide to air pollution*
www.londonair.org.uk/london/asp/information.asp?view=howbad
15 May 2006

<u>3.1 Pollutants which can be connected to vehicle emissions</u>

Carbon monoxide (CO) is a toxic gas that is mainly emitted by combustion processes, for example from vehicles. CO is also, to a much smaller extent, produced naturally from the oxidation of various organic compounds. London Air Quality Network[7] estimates that road transport is responsible for almost 90 per cent of carbon monoxide emissions in the UK. Carbon monoxide survives in the atmosphere for approximately a month before it is eventually oxidised into carbon dioxide[8]. According to the Victoria Transport Policy Institute[9], carbon monoxide affects the human body by undermining the blood's ability to carry oxygen around the body. Exposure to carbon monoxide can also result in blockage of important biochemical reactions in cells.[10]

Nitrogen dioxide (NO_2) is created during fossil fuel combustion. Nitrogen dioxide, together with nitric oxide (NO), are commonly referred to as nitrogen oxides (NO_X). The

[7] www.londonair.org,uk/asp/information.asp?view=howbad 15 May 2006
[8] The UK National Air Quality Archive www.airquality.co.uk/archive/what_causes.php#co 9 May 2006
[9] www.vtpi.org 6 April 2006
[10] The Mayor's Air Quality Strategy www.london.gov.uk/mayor/strategies/air_quality/docs/chap_2.pdf 5 June 2006

majority of nitrogen oxides are emitted from vehicle exhausts in the form of nitric oxide (NO). Nitric oxide in itself is not considered harmful to humans but when this gas is emitted from the exhaust of a vehicle, it reacts with other gases present both in the exhaust and in the atmosphere itself. Nitrogen dioxide, which is harmful to human health, is produced when nitric oxide reacts with ozone (O_3). Consequently, concentrations of nitrogen dioxide depend very strongly on the background concentrations and on the availability of ozone (Berkowicz, 2000). How much of the nitric oxide is converted into nitrogen dioxide is of course a very important issue. It is however very difficult to perform any calculations on this subject. The fact that NO_2 is not directly emitted from vehicle exhausts makes this pollutant different from the other pollutants studied here. Even so, road transport is estimated to be responsible for about 50 per cent of total emissions of nitrogen oxides in the UK[11]. The remaining NO_X emissions can be attributed mainly to power stations. Since traffic is an important source of nitrogen dioxide, the levels of this substance can be expected to be highest close to busy roads and in large urban areas, such as central London.

Thanks to a decrease in coal burning and heavy industry coupled with improved industrial pollution control measures, the amount of *particulate matter* in urban areas has decreased rapidly over the last 30 years[12]. This can be illustrated by the fact that London no longer experiences the infamous smog that was very common in the 1950s. Attention is now focused on finer particles, known as PM10, which can be breathed deeply into the lungs and are more likely than larger particles to have a damaging effect on human health. Recently, focus has also been put on even finer particles, known as PM2.5. These small particles, which are made up of carbon from combustion and chemical compounds, can remain in the atmosphere for several weeks. This means that the particles can drift over large spaces and cause pollution away from the original source. The principal source of airborne PM10 matter in European cities is road traffic emissions, particularly from

[11] London Air Quality Network www.londonair.org.uk/london/asp/information/asp?view=whatis 27 April 2006
[12] London Air Quality Network www.londonair.org.uk/london/asp/information.asp?view=whatis 27 April 2006

diesel vehicles[13]. In the UK, PM10 level measurement has only been carried out for the last few years and PM2.5 monitoring has only recently commenced in a few areas of London[14]. Since the measurements of both PM10 and especially PM2.5 have been carried out for such a short period of time, it is not really possible to identify any significant trends.

"Hydrocarbons" is a term often used when discussing traffic pollution. The term refers to a group of chemicals of which volatile organic compounds (VOCs) are a subgroup. VOCs comprise of a range of chemical compounds including 1,3 butadiene (C_4H_6) and benzene (C_6H_6). 1,3 butadiene is emitted primarily from fuel combustion in petrol and diesel engines but is also produced by certain industrial processes[15] while benzene is created either during the combustion or evaporation of fuel[16]. Combustion by petrol driven vehicles is the single biggest source of benzene emissions and accounts for about 70 per cent of total emissions[17]. As a result, the levels of these two chemicals are highest close to busy roads. Both 1,3 butadiene and benzene has a damaging impact on human health and both substances have been linked to leukaemia and other cancer forms[18]. In addition, animal studies have suggested that benzene is a genotoxic carcinogen meaning that it causes damage to the genetic make-up of cells.[19]The monitoring process for hydrocarbons is expensive and monitoring has only been carried out in the UK for the last few years. Therefore, as is the case with particulates, it is difficult to identify any trends in the levels of hydrocarbons.

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[13] The UK National Air Quality Information Archive www.airquality.co.uk/archive/what_causes.php#pm 9 May 2006

[14] London Air Quality Network www.londonair.org.uk/london/asp/information.asp?view=whatis 27 April 2006

[15] The Mayor's Air Quality Strategy www.london.gov.uk/mayor/strategies/air_quality/docs/chap_2.pdf 5 June 2006

[16] London Air Quality Network www.londonair.org.uk/london/asp/information.asp?view=whatis 27 April 2006

[17] The UK Air Quality Information Archive www.airquality.co.uk/archive/what_causes.php#pm 9 May 2006

[18] London Air Quality Network www.londonair.org.uk/london/asp/information.asp?view=whatis 27 April 2006

[19] The Mayor's Air Quality Strategy www.london.gov.uk/mayor/strategies/air_quality/docs/chap_2.pdf 5 June 2006

3.2 UK meteorological conditions in 2003

During most of 2003, the UK experienced a period of statistically unusual weather conditions. Northern Europe is part of the so-called west wind belt, where winds originating from the west and southwest are more common than winds originating from any other direction[20]. The country experienced an unusually hot summer and the proportion of winds that originated from the east over the entire year were approximately double that of 2001 and 2002. This is a statistically unusual occurrence. Such conditions imply dry, slow-moving and stable air that is particularly conducive to the build-up of pollution episodes (TfL, 2004). Easterly winds usually originate over central Europe and such air often carry relatively high concentrations of pollutants, especially PM10 and ozone. In 2003, record levels of ozone were imported with the winds from continental Europe and this facilitated greater production of nitrogen dioxide (TfL, 2004). These unusual meteorological conditions can also be seen as the primary reason for the large number of PM10 episodes in London following the introduction of the congestion charge. These episodes resulted in large increases in days when recorded PM10 levels exceeded the National Air Quality Objective (TfL, 2005).

Keeping in mind these weather conditions, data taken from 2003 do not really give an accurate picture of what impact the congestion charge may have had on air quality in London. Both 2004 and 2005 have exhibited more normal conditions and data from these years will probably give a more accurate indication of any possible effects of the congestion charge on London's air quality.

4. Data

Daily data on five pollutants that can be connected to vehicle emissions were obtained from the UK National Air Quality Information Archive[21]. The UK National Air Quality Information Archive website was developed by NETCEN, part of AEA Technology

[20] Nordiska ministerrådets rapport till Nordiska rådets internationella konferens om luftföroreningar: Europas luft – Europas miljö(1986) p. 17

[21] www.airquality.co.uk /archive/ index.php 3 – 5 May 2006

Environment, on behalf of the UK Department for Environment, Food and Rural Affairs and the Devolved Administrations. The pollutants studied in this paper are carbon monoxide, nitric oxide, nitrogen dioxide, benzene and 1,3 butadiene. Particulate matter (PM10 and PM 2,5) has been excluded as the UK National Air Quality Information Archive do not have any data on these pollutants prior to the introduction of the congestion charge and hence it is not possible to make any comparisons before and after the charge was introduced.

Daily data on carbon monoxide, nitric oxide and nitrogen dioxide obtained from the UK National Air Quality Information Archive were taken from the Westminster monitoring site, well inside the congestion zone, for the time period 17th July 2001 to 31st of March 2006. The reason for the start date is simply that the UK National Air Quality Information Archive has no data available for these three pollutants at the Westminster site before the 17th of July 2001. Data on these pollutants was also obtained from the Marylebone Road site, just on the edge of the congestion charging zone, for the period 1st January 2001 to 31st March 2006. Nitric oxide and nitrogen dioxide levels are measured in μgm^{-3} while carbon monoxide levels are measured in mgm^{-3}. Benzene and 1,3 butadiene data were taken from the Marylebone Road site between 1st January 2001 and 31st March 2006 and measured in μgm^{-3}. Benzene and 1,3 butadiene levels are currently only monitored at two sites in London (the other site being Eltham in south London) and although Marylebone Road is just at the edge of the congestions zone, rather than in the actual zone, data from this site should give an indication of a possible congestion charging effect on air quality due to its close proximity to the congestion zone. Both benzene and 1,3 butadiene levels are measured in μgm^{-3}. The data from 2006 is provisional data that has not been fully ratified.

4.1 Air quality monitoring methods

Generally speaking, there two types of monitoring methods that can be used to monitor air pollution. These two methods are automatic and non-automatic monitoring methods. Non-automatic methods are generally cheaper and easier to operate but do not give as much accuracy and resolution as automatic methods[22]. The data on the relevant pollutants used in this study, obtained from the UK National Air Quality Information Archive, is automatic monitoring data. This means that the data is being collected from the individual sites by modem as opposed to non-automatic monitoring methods when the data is collected by some physical mean, such as diffusion tubes or filters, and then subject to chemical analysis with final pollutant concentrations calculated from these results[23].

5. Results and analysis

Using the data obtained from the UK National Air Quality Information Archive, a regression analysis was performed to find out if the introduction of a congestion charge in central London has had any impact, positive or negative, on the city's air quality. Regression analysis is concerned with the study of the relationship between one variable called the explained, or dependent, variable and one or more other variables called independent, or explanatory, variables (Gujarati, 1999, p. 123). The pollutant, CO, NO, NO_2, benzene and 1,3 butadiene respectively, was set as the dependent variable. The days of the week were set as independent variables, not including Sunday which was set as the baseline. Using the weekdays as independent variables means that variation in pollution levels across the week can be captured. This is interesting since the congestion charge does not apply every day of the year and variation can be expected. In the regression output, day 2 equals Monday etc. The coefficient show the air pollution on a particular day of the week compared to the pollution level on Sundays, when the concentrations can be expected to be at its lowest. A dummy variable, which is qualitative, rather than quantitative, in nature (Gujarati, 1999 p. 275), was also included, taking on the value of one for dates after the 17th of February 2003 (the introduction date of the charge) and zero for all dates prior to the introduction of the congestion charge.. The regression

[22] London Air Quality Network www.londonair.org.uk/london/asp/information.asp?view=howmonitor 12 May 2006
[23] The UK National Air Quality Information Archive www.airquality.co.uk/archive/data_and_statistics_home.php 15 May 2006

results, obtained from the econometric software program, Eviews, are presented in the appendix.

Generally, when performing regression analysis, the interest lies in testing the statistical significance of the model used. That is to say, one wants to find out if there is a significant relationship between the dependent variable and the independent variable(s) used in that particular model (Körner & Wahlgren, 2000, p. 359). In a general model including two independent variables, the null hypothesis can be written as

$$H_0: \beta_1 = 0 \text{ and } \beta_2 = 0$$

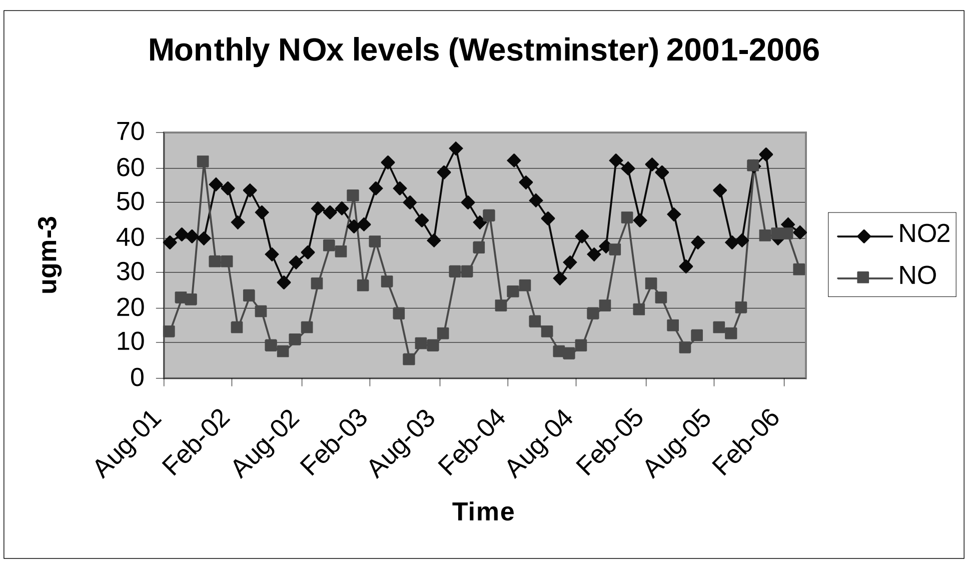
If the null hypothesis is true it means that there is no relationship between the dependent variable and the independent variables (Körner & Wahlgren, 2000, p. 359). This hypothesis is so important that econometric software automatically reports the results of this test (Hill et al, 2001, p.107). Whether or not the results obtained are significant can be seen looking at the probability (p) value in the regression results output (see appendix). A probability value of less than 5% (0.05) indicates that the null hypothesis can be rejected (Körner & Wahlgren, 2000, p. 359) and it can consequently be concluded that the result obtained is significant.

5.1 Nitrogen dioxide and nitric oxide

Seen over the entire period, the levels of nitrogen dioxide have significantly increased at both the Westminster and Marylebone Road monitoring sites. Looking at the levels of NO, the data observed at the Marylebone Road site actually indicate a significant decrease in NO concentrations. The concentrations at the Westminster monitoring site appear to be falling but the result is not statistically significant. A possible explanation to why NO_2 levels have increased even though decreasing concentrations of NO have been observed may be found in the levels of ozone. As explained in section 3.1, the concentration of nitrogen dioxide present in the air depends very much on the availability of ozone. High ozone levels could consequently be used to explain why nitrogen dioxide levels have increased even though the levels of nitric oxide have not.

These results deviate from the decrease that would be expected as a result of a congestion charging scheme. Data on "exceedances" (when the air quality standards and objectives are exceeded), obtained from the UK Air Quality Information Archive for the period January 2001 – March 2006, show that the levels of nitrogen dioxide have continuously been exceeding the air quality objectives as well as the air quality standards. The air quality objective of an annual mean concentration of less than 40 µgm-3 was exceeded at 17 monitoring sites in 2001, 15 sites in 2002, 13 sites in 2003, 15 sites in 2004, and 16 sites in 2005 and up until the 31st March 2006 the objective has been exceeded at 11 monitoring sites this year.[24] Figure 2 shows the monthly concentrations of both nitric oxide and nitrogen dioxide between August 2001 and March 2006 at the Westminster monitoring site while figure 3 shows the corresponding figures from the Marylebone Road monitoring site between January 2001 and March 2006.

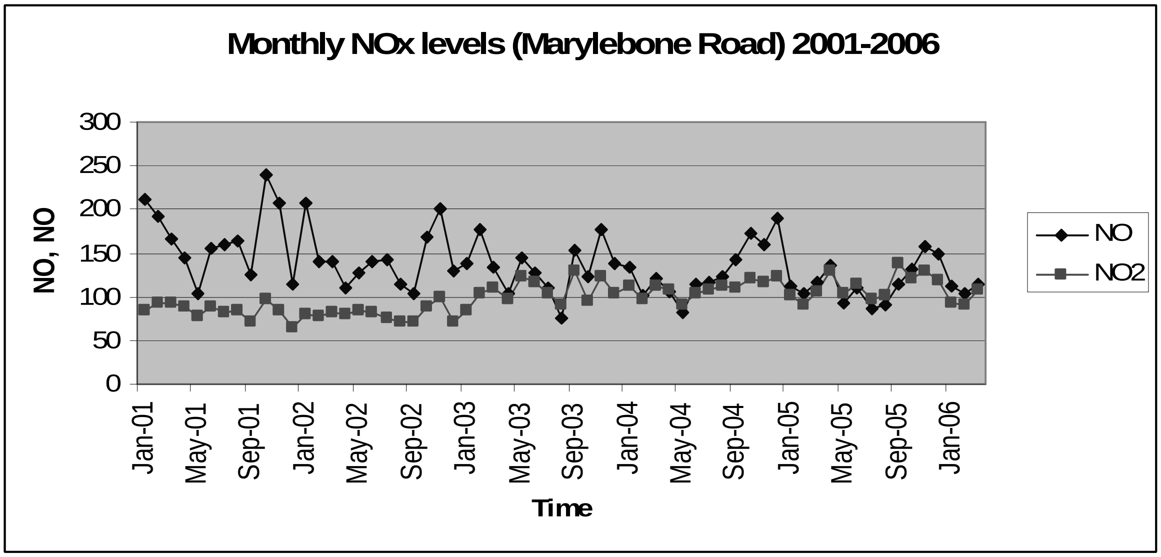
Figure 2: Monthly NO_X levels (Westminster) August 2001 – March 2006



Source: http://www.airquality.co.uk/archive/data_and_statistics_home.php

[24] The UK Air Quality Information Archive http://www.airquality.co.uk/archive/data_and_statistics.php 31-05-2006

Figure 3: Monthly NO_X levels (Marylebone Road) August 2001 – March 2006



Source: http://www.airquality.co.uk/archive/data_and_statistics_home.php

From these graphs, it is difficult to establish any clear trends, rising or falling, in the concentrations of NO_X in the London Westminster area. However, the congestion charge has still only been in place for a relatively short period of time, just over three years, and environmental benefits are difficult to estimate after this short period of time. A study carried out in the future may be able to establish a clearer trend, hopefully one of falling NO_X concentrations.

A possible reason that the concentration of NO_X pollutants in the air in central London does not appear to have fallen since the introduction of the congestion charge may be the change in the composition of vehicles now entering the congestion zone. Although the number of cars entering the congestion zone each day has fallen since the introduction of the charge, the number of buses travelling within the congestion zone has increased. Prior to the introduction of the congestion charge, TfL predicted that 20 000 individuals would switch from car travel to public transport during the morning peak hours as a direct result of the congestion charging scheme. Of these 20 000 individuals, 5000 were expected to start using the underground, 14 000 to switch from car to bus and the remaining 1000 were expected to use the rail system. During the first year of operation, bus use did rise in line with TfL's expectations (Blake & Shaffer, 2003). While the number of cars entering the congestion zone has fallen by 29 per cent since the introduction of the congestion charge, the number of buses travelling in the zone has increased by 20 per cent (Beevers & Carslaw, 2004). Diesel engines, commonly used in buses such as those serving central London, emit higher concentrations of NO_X pollutants than the petrol engines normally found in cars. Table 3 shows the percentage emission levels of NO_X and CO from a petrol-driven car without a catalyst and a heavy diesel-driven vehicle, such as a bus.

Table 3: Emission levels

	Car	Heavy diesel-driven vehicle
NO_X	18	61
CO	72	21

Source: Möller (1990) p.15

This could imply that the part of the explanation why NO_X levels have not fallen in central London since the introduction of the congestion charge may lie in the change in the composition of vehicles entering the charged zone.

A further explanation may lie in the unusual meteorological conditions that the UK experienced during 2003. As a result of these unusual weather conditions, the annual concentration of NO_2 actually increased by 11 per cent (Beevers & Carslaw, 2004). However, surprisingly, the concentrations of nitric oxide and nitrogen dioxide (NO_X) actually continued to rise at many road side sites, both in and outside the congestion zone, during the following year as well (TfL, 2005). This represents a departure from long-established trends of falling levels of NO_X and may help explain why an increase, rather than a decrease, in the concentrations of these gases has been observed since the introduction of the congestion charge. This phenomenon is currently subject to ongoing investigation (TfL, 2005).

As nitrogen dioxide levels are closely connected to ozone levels, the reason why no decreases in concentrations have been observed since the introduction of the congestion charge may lie in changes in ozone levels. Data on ozone has not been studied in this paper but it is worth keeping in mind that these changes in the concentrations of this substance would result in changes in the levels of nitrogen dioxide as well.

As for the variation in the levels of nitrogen dioxide across the week, the results seem a bit ambiguous. Table 4, found in the appendix, show that before the congestion charge was implemented, the levels of nitrogen dioxide at the Westminster site was significantly higher than the Sunday levels on every day of the week. After the congestion charge was introduced, the levels of NO_2 fell on every day of the week except Monday, compared to Sunday levels. However, the results obtained after the congestion charge was implemented are not statistically significant.

At the Marylebone Road site (table 5), the concentrations of nitrogen dioxide was higher than Sunday's level on every day of the week. The results are statistically significant, except for on Saturdays. Similar results are found after the introduction of the congestion charge. Pollution levels are higher than Sunday levels on every day of the week. However, the only statistically significant result was obtained for Friday pollution levels. On the other days of the week, the results found were statistically insignificant.

5.2 Carbon monoxide

The results obtained from calculations using the data on carbon monoxide taken from the Marylebone Road monitoring site shows a significant fall in the concentrations of carbon monoxide present in the air at this monitoring site. Falling levels of CO was also observed at the Westminster site although this result was not significant. These results correspond to what would be expected following the introduction of a congestion charge in London as road transport is estimated to be responsible for almost 90 per cent of the UK's carbon monoxide emissions. The results obtained are also in line with the London Air Quality Network's monitoring data, which suggests that average CO levels have been decreasing over the last few years[25]

[25] www.londonair.org.uk/asp/information.asp?howbad 15 May 2006

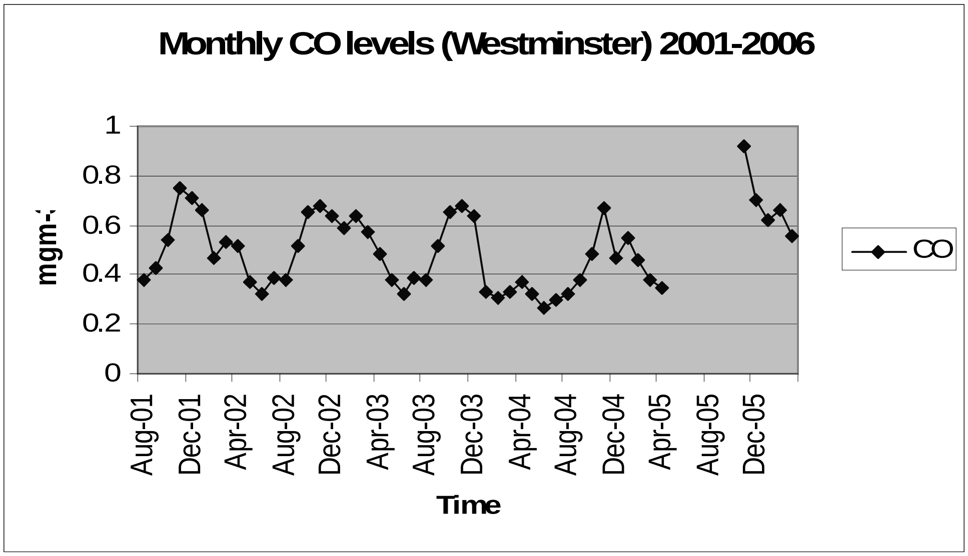
The change in composition of the vehicles entering the congestion charging zone would be expected to result in lower levels of CO in the air. As shown in table 3 (previous page), diesel-driven vehicles, such as buses, of which there are a larger number present in the congestion zone after the charge was introduced, emits significantly lower levels of carbon monoxide than do petrol-driven vehicles. As a result of decreasing numbers of petrol-driven vehicles, coupled with the increase in diesel-driven buses, lower levels of carbon monoxide can be expected to be present in the air in central London.

It is also worth noting that CO levels have not exceeded the air quality standard of an 8-hour running mean of less than 10 mgm^{-3} at any point during the period January 2001 – March 2006. In other words, the concentrations of carbon monoxide present in the air in central London were not high enough to threaten human health even before the introduction of the congestion charge. Nevertheless, falling concentrations of pollutants are obviously always desirable from an environmental point of view.

The variation in pollution levels across the week can be found in table 8 (Westminster monitoring site) and table 9 (Marylebone Road monitoring site). Table 8 show that the CO levels were higher than Sunday levels on every day of the week prior to the introduction of the congestion charge. However, the only significant results were obtained on Friday and Saturday. After the congestion charge came into place, the pollution levels are lower compared to Sunday level on every day of the week. These results are, however, statistically insignificant. At the Marylebone Road monitoring site, no significant results on the variation of pollution levels over the course of the week were obtained.

The monthly levels of carbon monoxide observed at the Westminster site between August 2001 and March 2006 can be found in figure 3. As can be seen from this figure, at the end of 2005 several months of data on CO levels are missing and it is hard to identify any clear trends from this figure.

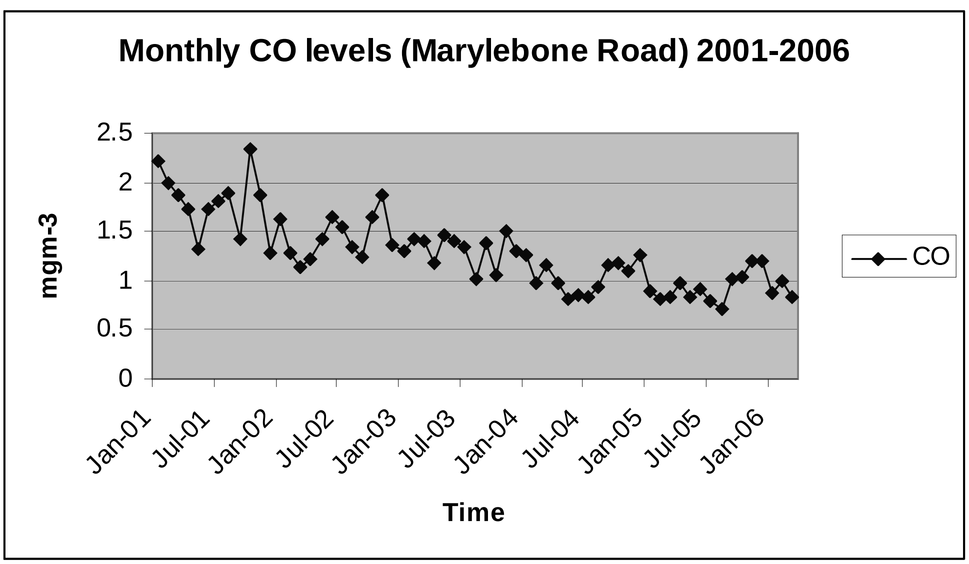
Figure 4: Monthly CO levels (Westminster) August 2001 – March 2006



Source: http://www.airquality.co.uk/archive/data_and_statistics_home.php

The monthly concentrations of carbon monoxide at the Marylebone Road monitoring site are shown in figure 4. At this monitoring site, the data set is complete and the falling trend is much easier to identify.

Figure 5: Monthly CO levels (Marylebone Road) January 2001 – March 2006



Source: http://www.airquality.co.uk/archive/data_and_statistics_home.php

5.3 Hydrocarbons – benzene and 1,3 butadiene

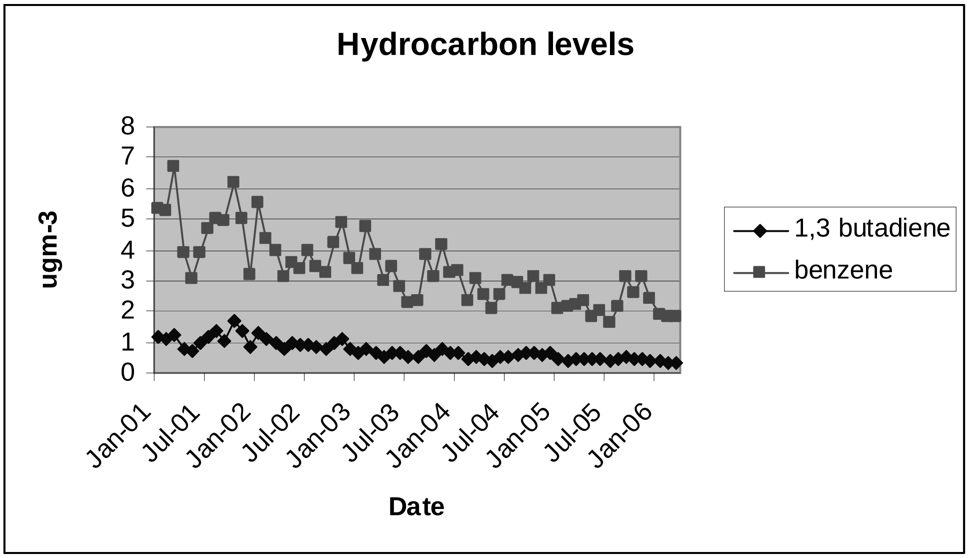
The results obtained from the regression analysis performed using data on benzene concentrations show significant falls in the concentrations of benzene at the Marylebone Road monitoring site since the introduction of the congestion charge. The concentration of 1,3 butadiene has also fallen significantly at the Marylebone Road site since the congestion charge was introduced.

As petrol-driven vehicles is the single biggest source of benzene emissions in the UK[26], the change in the composition of vehicles entering the congestion zone before and after the introduction of the congestion charge can once again be used to explain the falling concentrations of this pollutant. Fewer petrol-driven vehicles entering the congestion charging zone would mean lower benzene emissions in the zone. Even though hydrocarbon levels are measured on the edge of the congestion zone (there is no congestion charge on the Marylebone Road although it is part of its boundary), the close proximity to the congestion zone means that the possible effects of the congestion scheme can also be detected here. The levels of 1,3 butadiene, emitted from both petrol and diesel engines, can also be expected to be affected in a positive way as a result of the reduced number of vehicles in the congestion zone.

The monthly average levels of hydrocarbons observed in the air at the Marylebone Road site between January 2001 and March 2006 can be found in figure 4. This illustrates the falling concentrations of both pollutants observed in the air but, as the congestion charge has only been in place for just over three years, it may be too early to attribute this fall to a congestion charging effect. There could be other factors contributing to these falling trends. Nevertheless, the falling levels are encouraging. It is also worth noting that neither the levels of benzene nor the levels of 1,3 butadiene has exceeded the air quality strategy objective at any time during the period January 2001 to March 2006.

[26] London Air Quality Networkwww.londonair.org.uk/london/asp/information.asp?view=whatis 27 April 2006

Figure 6: Monthly hydrocarbon levels January 2001 – March 2006



Source: http://www.airquality.co.uk/archive/data_and_statistics_home.php

The variation in benzene levels across the week can be found in table 10. Unfortunately, no statistically significant results can be found here. As for 1,3 butadiene, the results can be found in table 11. Prior to the congestion charge, the pollution levels appear to have been lower during the week compared to Sunday levels, although only the result for Monday and Wednesday are statistically significant. After the introduction of the charge, the levels of 1,3 butadiene increased compared to Sunday levels on every day of the week. Again, not all results obtained were statistically significant. The results obtained for Monday, Wednesday and Thursday were statistically significant while the remaining results were insignificant.

6. Conclusion

There is no doubt that the congestion charging scheme in central London has been successful in achieving the objectives set before its implementation. Notably, road usage fell significantly already in the first year, from 1,390 thousand vehicle km per day in 2002 to 1,160 vehicle km per day in 2003 (Prud'Homme & Bocarejo, 2005). This represents 16,5 per cent decrease in road usage since the introduction of the charge in February 2003. The congestion charging scheme has, so far, achieved the goals set out in every year since its introduction and the majority of Londoners are satisfied with the system. A simple, feasible and transparent system means that there has been surprisingly little public backlash following its introduction. A survey by Market and Opinion Research showed that 50 per cent of residents in London support the congestion scheme and 73 per cent believes that it has been effective when it comes to reducing congestion (Shaffer & Santos, 2003). The Londoners' satisfaction with the scheme can also be illustrated by the fact that Ken Livingstone, the man responsible for the introduction of the congestion charge, was re-elected as Mayor of London in 2004.

It is however less clear if, and how much, a congestion charging scheme can help improve the air quality in London's rather polluted city centre. Logically, a reduced number of vehicles in the congestion zone should result in reduced emissions and this in turn would mean lower concentrations of pollutants in the air. The results presented in this paper, however, show limited evidence that the concentration of air pollutants have fallen in central London since the introduction of the charge. Carbon monoxide, benzene and 1,3 butadiene levels have significantly decreased since the introduction of the congestion charge. For nitrogen dioxide however, no decreases have been observed. This result is particularly important since nitrogen dioxide is the only one of the pollutants studied in this paper that keeps consistently exceeding its air quality objectives. This implies that NO_2 concentrations may be the most important to focus on reducing as this pollutant seems to be the biggest threat to human health in the London area at the moment. Saying this, it is important to keep in mind that the charge has only been in place for just over three years and that it is hard to observe environmental changes like these in the short and medium term. Weather conditions play an important role in the measuring of air pollutants. Once the pollutant is emitted it may travel from the source of emission and where it goes depends on the direction and speed of the winds. Unfavourable weather conditions can cause pollution levels to rise by up to ten times.[27] The statistically unusual weather conditions the UK experienced during 2003 means that data from this year will not really reflect any effect of the congestion charge.

This study has nevertheless shown some decreases in pollution levels in the central London area and these results are obviously encouraging. However, a study of the effects the congestion charging scheme may have had on London's air quality carried out in 15 or even 20 years time, is likely to generate even more decisive results of the effects on air quality as the charge will then have been in place for a longer period of time and a much larger amount of data can be studied.

[27] London Air Quality Network www.londonair.org.uk/london/asp/information.asp?view=howbad 15 May 2006

7. Appendix

7.1 Regression results

Table 4: NO_2 (Westminster monitoring site)

Dependent Variable: NO2
Method: Least Squares
Date: 05/04/06 Time: 11:20
Sample: 7/17/2001 3/31/2006
Included observations: 1416

Variable	Coefficient	Std. Error	t-Statistic	Prob.
DAY=2	9.356698	2.758579	3.391854	0.0007
DAY=3	12.30783	2.748994	4.477211	0.0000
DAY=4	13.56218	2.758579	4.916364	0.0000
DAY=5	16.14815	2.730487	5.914019	0.0000
DAY=6	13.97103	2.712813	5.150016	0.0000
DAY=7	7.402597	2.721549	2.719994	0.0066
DUMMY	5.585221	2.431868	2.296679	0.0218
(DAY=2)*DUMMY	0.955821	3.473572	0.275169	0.7832
(DAY=3)*DUMMY	-0.743340	3.465965	-0.214468	0.8302
(DAY=4)*DUMMY	-1.423012	3.476136	-0.409366	0.6823
(DAY=5)*DUMMY	-5.641116	3.456506	-1.632029	0.1029
(DAY=6)*DUMMY	-3.864377	3.445231	-1.121660	0.2622
(DAY=7)*DUMMY	-2.662943	3.436708	-0.774853	0.4386
C	33.25974	1.924426	17.28294	0.0000

R-squared	0.076876	Mean dependent var	45.91596
Adjusted R-squared	0.068316	S.D. dependent var	17.49494
S.E. of regression	16.88677	Akaike info criterion	8.500776
Sum squared resid	399798.6	Schwarz criterion	8.552738
Log likelihood	-6004.549	F-statistic	8.981218
Durbin-Watson stat	0.577805	Prob(F-statistic)	0.000000

Table 5: NO_2 (Marylebone Road monitoring site)

Dependent Variable: NO2
Method: Least Squares
Date: 05/10/06 Time: 12:16
Sample: 1/01/2001 3/31/2006
Included observations: 1847

Variable	Coefficient	Std. Error	t-Statistic	Prob.
DAY=2	13.60705	4.412271	3.083910	0.0021
DAY=3	20.90654	4.432651	4.716487	0.0000
DAY=4	17.44950	4.464503	3.908497	0.0001
DAY=5	19.58411	4.443093	4.407765	0.0000
DAY=6	17.57009	4.432651	3.963789	0.0001
DAY=7	6.047075	4.422378	1.367381	0.1717
DUMMY	18.07774	4.064440	4.447782	0.0000
(DAY=2)*DUMMY	9.380091	5.736026	1.635294	0.1022
(DAY=3)*DUMMY	11.62483	5.737055	2.026271	0.0429
(DAY=4)*DUMMY	14.85365	5.780063	2.569807	0.0103
(DAY=5)*DUMMY	18.12926	5.756042	3.149606	0.0017
(DAY=6)*DUMMY	8.565308	5.755496	1.488196	0.1369
(DAY=7)*DUMMY	1.336653	5.732727	0.233162	0.8157
C	68.91589	3.134358	21.98724	0.0000

R-squared	0.223150	Mean dependent var	98.66973
Adjusted R-squared	0.217641	S.D. dependent var	36.65535
S.E. of regression	32.42205	Akaike info criterion	9.803105
Sum squared resid	1926830.	Schwarz criterion	9.844956
Log likelihood	-9039.168	F-statistic	40.50232
Durbin-Watson stat	0.930347	Prob(F-statistic)	0.000000

Table 6: NO (Westminster monitoring site)

Dependent Variable: NO
Method: Least Squares
Date: 05/09/06 Time: 11:31
Sample: 7/17/2001 3/31/2006
Included observations: 1490

Variable	Coefficient	Std. Error	t-Statistic	Prob.
DAY=2	10.56164	4.203340	2.512679	0.0121
DAY=3	11.93243	4.188736	2.848695	0.0045
DAY=4	13.09589	4.203340	3.115591	0.0019
DAY=5	17.03947	4.160536	4.095500	0.0000
DAY=6	18.41026	4.133604	4.453802	0.0000
DAY=7	10.85714	4.146917	2.618124	0.0089
DUMMY	2.323741	3.655357	0.635708	0.5251
(DAY=2)*DUMMY	0.778849	5.221490	0.149162	0.8814
(DAY=3)*DUMMY	0.374261	5.206378	0.071885	0.9427
(DAY=4)*DUMMY	-2.397734	5.221490	-0.459205	0.6462
(DAY=5)*DUMMY	-6.844967	5.187094	-1.319615	0.1872
(DAY=6)*DUMMY	-7.681759	5.175980	-1.484117	0.1380

(DAY=7)*DUMMY	-5.995170	5.166164	-1.160468	0.2460
C	13.00000	2.932313	4.433360	0.0000

R-squared	0.033107	Mean dependent var	24.17114
Adjusted R-squared	0.024591	S.D. dependent var	26.05328
S.E. of regression	25.73094	Akaike info criterion	9.342617
Sum squared resid	977232.2	Schwarz criterion	9.392477
Log likelihood	-6946.250	F-statistic	3.887638
Durbin-Watson stat	0.708886	Prob(F-statistic)	0.000003

Table 7: NO (Marylebone Road monitoring site)

Dependent Variable: NO
Method: Least Squares
Date: 05/10/06 Time: 12:04
Sample: 1/01/2001 3/31/2006
Included observations: 1849

Variable	Coefficient	Std. Error	t-Statistic	Prob.
DAY=2	32.75890	10.41506	3.145338	0.0017
DAY=3	50.91589	10.46317	4.866201	0.0000
DAY=4	41.12904	10.53836	3.902795	0.0001
DAY=5	52.70887	10.48782	5.025723	0.0000
DAY=6	55.32710	10.46317	5.287795	0.0000
DAY=7	17.05426	10.43892	1.633718	0.1025
DUMMY	-33.03828	9.594016	-3.443634	0.0006
(DAY=2)*DUMMY	6.973588	13.53092	0.515382	0.6063
(DAY=3)*DUMMY	7.132201	13.54219	0.526665	0.5985
(DAY=4)*DUMMY	15.00130	13.64370	1.099504	0.2717
(DAY=5)*DUMMY	14.52680	13.58700	1.069169	0.2851
(DAY=6)*DUMMY	-6.659783	13.57680	-0.490527	0.6238
(DAY=7)*DUMMY	-1.131011	13.53197	-0.083581	0.9334
C	118.1402	7.398579	15.96796	0.0000

R-squared	0.099228	Mean dependent var	137.1644
Adjusted R-squared	0.092847	S.D. dependent var	80.35258
S.E. of regression	76.53149	Akaike info criterion	11.52082
Sum squared resid	10747723	Schwarz criterion	11.56264
Log likelihood	-10637.00	F-statistic	15.54938
Durbin-Watson stat	0.955764	Prob(F-statistic)	0.000000

Table 8: CO (Westminster monitoring site)

Dependent Variable: CO
Method: Least Squares
Date: 05/09/06 Time: 11:28
Sample: 7/17/2001 3/31/2006
Included observations: 1469

Variable	Coefficient	Std. Error	t-Statistic	Prob.
DAY=2	0.035987	0.038354	0.938293	0.3482
DAY=3	0.048718	0.038226	1.274474	0.2027
DAY=4	0.030353	0.038101	0.796644	0.4258
DAY=5	0.048750	0.037859	1.287685	0.1981
DAY=6	0.074275	0.037742	1.967979	0.0493
DAY=7	0.077978	0.037742	2.066113	0.0390
DUMMY	-0.056884	0.033830	-1.681467	0.0929
(DAY=2)*DUMMY	-0.001314	0.048372	-0.027166	0.9783
(DAY=3)*DUMMY	-0.012793	0.048306	-0.264822	0.7912
(DAY=4)*DUMMY	-0.004141	0.048172	-0.085970	0.9315
(DAY=5)*DUMMY	-0.027554	0.048016	-0.573842	0.5662
(DAY=6)*DUMMY	-0.049995	0.047853	-1.044768	0.2963
(DAY=7)*DUMMY	-0.066498	0.047784	-1.391635	0.1642
C	0.483750	0.026770	18.07054	0.0000

R-squared	0.031391	Mean dependent var	0.478965
Adjusted R-squared	0.022737	S.D. dependent var	0.242208
S.E. of regression	0.239439	Akaike info criterion	-0.011552
Sum squared resid	83.41665	Schwarz criterion	0.038886
Log likelihood	22.48464	F-statistic	3.627217
Durbin-Watson stat	0.655217	Prob(F-statistic)	0.000011

Table 9: CO (Marylebone Road monitoring site)

Dependent Variable: CO
Method: Least Squares
Date: 05/10/06 Time: 11:28
Sample: 1/01/2001 3/31/2006
Included observations: 1860

Variable	Coefficient	Std. Error	t-Statistic	Prob.
DAY=2	-0.115142	0.075344	-1.528213	0.1266
DAY=3	-0.003937	0.075517	-0.052139	0.9584
DAY=4	-0.040328	0.075870	-0.531537	0.5951
DAY=5	0.003338	0.076052	0.043888	0.9650

DAY=6	0.062617	0.075692	0.827256	0.4082
DAY=7	-0.097711	0.075344	-1.296859	0.1948
DUMMY	-0.601183	0.069315	-8.673142	0.0000
(DAY=2)*DUMMY	0.131598	0.097758	1.346151	0.1784
(DAY=3)*DUMMY	0.086762	0.097768	0.887428	0.3750
(DAY=4)*DUMMY	0.125252	0.098291	1.274292	0.2027
(DAY=5)*DUMMY	0.115379	0.098243	1.174427	0.2404
(DAY=6)*DUMMY	0.000674	0.098027	0.006879	0.9945
(DAY=7)*DUMMY	0.079285	0.097634	0.812062	0.4169
C	1.625234	0.053522	30.36547	0.0000

R-squared	0.184270	Mean dependent var	1.285161
Adjusted R-squared	0.178525	S.D. dependent var	0.610844
S.E. of regression	0.553640	Akaike info criterion	1.662896
Sum squared resid	565.8316	Schwarz criterion	1.704507
Log likelihood	-1532.493	F-statistic	32.07717
Durbin-Watson stat	0.846698	Prob(F-statistic)	0.000000

Table 10: Benzene (Marylebone Road monitoring site)

Dependent Variable: BENZENE
Method: Least Squares
Date: 05/09/06 Time: 11:22
Sample (adjusted): 1/01/2001 3/28/2006
Included observations: 1684 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
DAY=2	-0.438367	0.225669	-1.942525	0.0522
DAY=3	-0.136571	0.227443	-0.600463	0.5483
DAY=4	-0.301804	0.225098	-1.340765	0.1802
DAY=5	0.004201	0.223987	0.018755	0.9850
DAY=6	-0.023720	0.223987	-0.105899	0.9157
DAY=7	-0.403720	0.223987	-1.802428	0.0717
DUMMY	-1.824245	0.207752	-8.780866	0.0000
(DAY=2)*DUMMY	0.547691	0.294684	1.858568	0.0633
(DAY=3)*DUMMY	0.377681	0.293557	1.286568	0.1984
(DAY=4)*DUMMY	0.537478	0.294940	1.822331	0.0686
(DAY=5)*DUMMY	0.415417	0.292303	1.421184	0.1554
(DAY=6)*DUMMY	0.164185	0.291885	0.562500	0.5739
(DAY=7)*DUMMY	0.290574	0.291885	0.995508	0.3196
C	4.378571	0.159572	27.43949	0.0000

R-squared	0.186489	Mean dependent var	3.315398
Adjusted R-squared	0.180156	S.D. dependent var	1.744633
S.E. of regression	1.579681	Akaike info criterion	3.760602
Sum squared resid	4167.307	Schwarz criterion	3.805736

Log likelihood	-3152.427	F-statistic	29.44851
Durbin-Watson stat	0.914700	Prob(F-statistic)	0.000000

Table 11: 1,3 butadiene (Marylebone Road monitoring site)

Dependent Variable: BUTADIENE
Method: Least Squares
Date: 05/09/06 Time: 11:38
Sample (adjusted): 1/01/2001 3/28/2006
Included observations: 1739 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
DAY=2	-0.117937	0.046912	-2.514029	0.0120
DAY=3	-0.077742	0.047279	-1.644331	0.1003
DAY=4	-0.096180	0.046678	-2.060517	0.0395
DAY=5	-0.052938	0.046452	-1.139632	0.2546
DAY=6	-0.034893	0.046678	-0.747532	0.4548
DAY=7	-0.076530	0.046452	-1.647520	0.0996
DUMMY	-0.570011	0.042832	-13.30809	0.0000
(DAY=2)*DUMMY	0.134990	0.060791	2.220564	0.0265
(DAY=3)*DUMMY	0.116201	0.060828	1.910325	0.0563
(DAY=4)*DUMMY	0.123784	0.060610	2.042296	0.0413
(DAY=5)*DUMMY	0.123987	0.060351	2.054416	0.0401
(DAY=6)*DUMMY	0.067171	0.060402	1.112053	0.2663
(DAY=7)*DUMMY	0.075208	0.060228	1.248718	0.2119
C	1.074200	0.033088	32.46481	0.0000

R-squared	0.340262	Mean dependent var	0.724071
Adjusted R-squared	0.335290	S.D. dependent var	0.405841
S.E. of regression	0.330881	Akaike info criterion	0.633904
Sum squared resid	188.8572	Schwarz criterion	0.677869
Log likelihood	-537.1795	F-statistic	68.43640
Durbin-Watson stat	0.769804	Prob(F-statistic)	0.000000

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