THE ECONOMIC BENEFITS OF REDUCING TRAFFIC-RELATED POLLUTION NEAR PRIMARY SCHOOLS: THE CASE OF LONDON.

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Abstract

There is now sufficient epidemiological evidence to suggest a causal relationship between traffic-related air pollution exposure and asthma exacerbation in children. Providing a healthy school environment is a priority for child health. The objective of this study is to develop a methodology that allows quantification of the potential economic benefit of reducing indoor exposure to traffic-related pollution in children attending primary schools. Using environmental and health data collected in primary schools in London, this study estimates the yearly number of asthma exacerbations that can be prevented in each primary school located in proximity to a traffic polluted area in London. Using a willingness to pay approach, the study quantifies the potential monetary benefits of reducing indoor nitrogen dioxide (NO_2) exposure based on three different perspectives: children's perspective adjusted for parents' budget, parents' perspective and children's perspective based on children's budget. The study expands upon previous analyses in two ways: first it assesses the health benefits of reducing children's exposure to traffic-related air pollution while at school, second it considers the children's perspective in the economic evaluation. Findings of this study indicate that designers, engineers, policymakers and stakeholders need to consider the reduction of outdoor pollution, and particularly NO_2 levels, near primary schools as there may be substantial health and monetary benefits.

Keywords: Traffic air pollution, Children health, monetary benefits, primary schools, London

1. Introduction

Over the past few decades, research evidence regarding the effects of traffic-related air pollution on human health has been mounting.(Health Effect Institute 2010). Previous economic evaluations conducted on the potential human health benefits of reducing traffic related air pollution showed that there is a strong economic incentive to improve air quality. A study conducted by Kunzli et al. quantified the health costs associated with traffic-related air pollution in three European countries: Austria, France and Switzerland. It showed that air pollution related costs of all three countries amounted to some €49,400 million and that road traffic alone was responsible for €26,400 million (Künzli et al. 1999).

Given the high vulnerability of children to environmental hazards there is an increasing number of economic evaluations assessing environmental health interventions targeting youth health (Pruss-Ustun A and Corvalan A 2006). Previous economic evaluations estimating the burden of childhood asthma associated with exposure to traffic pollution in Southern California (USA) suggest that the potential monetary benefit of reducing air pollution is high: US$2,765,520 and US$6,110,400 in Riverside and Long Beach respectively(Brandt et al. 2012). A more recent study conducted in ten European cities showed that the potential monetary benefit of reducing traffic-related pollution is even higher because of the higher traffic densities and proportion of urban dwellers living in proximity to busy roads compared to US urban areas (Perez L. et al. 2013). On average, Perez et al. estimated that up to 14% of all asthma episodes are attributable to exposure to traffic-related pollution (Perez L. et al. 2013).

Apart from the home, schools are where children spend most of their waking hours and may engage in physical activity that would increase inhalation rates and dose of pollutants(Eurostat 2011). A systematic meta-analysis of current evidence showed that school exposure to NO_2 is associated with an increased risk of prevalence and incidence of childhood asthma (Gasana J. et al. 2012). Despite the importance of providing healthy environments for children in school, there are no economic evaluations of interventions to reduce traffic-related air pollution close to primary schools.

Using indoor and outdoor pollution data collected in London primary schools as part of the project "Schools Indoor Pollution and Health: Observatory Network in Europe" (SINPHONIE), this paper estimates the burden of preventable childhood asthma under reduced exposure to indoor NO_2; secondly using willingness to pay values from both a parent and a child perspective, it quantifies the potential monetary benefit of preventing traffic-related childhood asthma exacerbations in primary schools.

The rest of the paper is organized as follows: in the following section an outline of the methodology is presented together with a brief description of the data used to populate the analysis. The results of the baseline analysis together with the results of sensitivity analyses (deterministic and probabilistic) are presented in section 3, while sections 4 and 5 offer concluding observations outlining the limits of the study and the opportunity for further research. A brief description of the SINPHONIE database is provided in the Supplemental Material.

2. Methodology

A damage function analytical framework was used to value the health impact of reducing NO_2 exposure in pupils attending primary school in London. The framework combined environmental, health and economic data to quantify the potential monetary benefits of reducing NO_2 exposure in schools.

The analysis consisted of four steps; firstly to quantify the number of asthma exacerbations attributable to traffic-related air pollution in London primary schools. The second step was to assign a monetary value to the burden of childhood asthma that can be prevented by reducing indoor concentrations of NO_2. The economic value of a policy intervention depends on how long the policy is assumed to display its effect. The third step was to estimate the present value of the future monetary benefits arising from reduction in traffic-related air pollution.

In order to account for the high degree of uncertainty associated with the input parameters used in the study, the fourth component of the study involved an extensive sensitivity analysis (deterministic and probabilistic using Monte Carlo simulation) was performed to assess how variation in the parameters affects model results. The characteristics of the five schools (S1-S5, see Table 1) examined in the SINPHONIE study and the parameters used to populated the analysis are reported in Table 1. For further details on the dataset used and how the data were collected please see the Supplementary Material.

2.1 Health Benefits analysis: asthma exacerbations associated with traffic-related air pollution.

The yearly number of asthma exacerbations per school that can be prevented by reducing outdoor NO_2 concentrations was estimated in three consecutive steps:

The first step consisted of calculating the probability of having asthma-related symptoms for a decrease in 10 μg/m^3 of NO_2 using the following formula(Martuzzi M. et al. 2006):

$$P_{10} = \frac{\left(\frac{P_0}{1-P_0} * OR\right)}{\left[1 + \left(\frac{P_0}{1-P_0} * OR\right)\right]} - P_0$$

Where P_0 is the relevant background rate among children in primary school age and OR is the Odds Ratio of having experienced asthma related symptoms per 10 mg/m^3 NO_2. The background rate (P_0) used in the baseline analysis is the average prevalence of asthmatic children in the urban school (10.16) (Table 1). While the OR comes from the SINPHONIE (OR: 1.11, 95% confidence interval (CI): 1.04-1.19)(Chatzidiakou et al. 2015).

The second step was to estimate the average indoor NO_2 concentration (Xc) given the observed outdoor NO_2 concentration (X_0) and the fraction of NO_2 indoor related to outdoor traffic air pollution (I/O).

$$Xc = XO * I/O$$

The choice of the baseline concentrations of NO_2 is crucial in assessing the potential benefits for child health arising from lower outdoor traffic-related air pollution. The outdoor NO_2 concentration assumed in the baseline was the average NO_2 level observed by the SINPHONIE study in the winter season in urban schools: 43.7 μg/m^3 (SD:4.1)(Chatzidiakou et al. 2013a; Chatzidiakou et al. 2013b). The Indoor-Outdoor (I/O) ratio in the baseline was equal to the mean I/O ratio in urban schools: 0.7(SD:0.1) (Chatzidiakou et al. 2013a; Chatzidiakou et al. 2013b).

The number of asthma exacerbations per year in each school (Dc) is estimated by the following formula(Martuzzi M. et al. 2006):

$$D_c = N * P_{10} * G_d * T_e\left[\frac{(Xc - B)}{10}\right]$$

The above equation quantifies the annual number of additional asthma exacerbations (D_c) per N children subjected to category *c* of exposure. In this case, we assumed N to be equal to the average number of pupils of those schools included in the UK SINPHONIE sample (432 pupils SD: 83.31). G_d is the daily prevalence of asthma exacerbations among those who are asthmatic. Using data from the Clean Air for Europe study, G_d is assumed to be 10%, which is the mean daily prevalence of bronchodilator use by school children who reported having asthma symptoms in school environments during the winter season(Hurley F. et al. 2002). T_e is the time of exposure, which in our case is the number of days each year in which children are exposed to *c* levels of NO_2. In one year, there are at least 190 school days.

In order to estimate outdoor NO_2 concentrations over the academic year, measurements were obtained from a fixed monitoring station in proximity to the urban schools (Islington Upper Street, London Air Quality Network)(London Air Quality Network 2014). Average outdoor NO_2 during a typical school day (09:00 -15:00 on working days) value were above 60 $\mu g/m^3$ in 127 of the 194 days of the school year 2011-2012 (65 % of the time). The multilevel regression estimated that 84% of the variation in indoor NO_2 levels is explained by outdoor levels, and therefore outdoor levels are a reliable predictor of indoor levels across seasons(Banerjee and Annesi-Maesano 2012; Chatzidiakou et al. 2015). Xc is the average NO_2 indoor concentrations in schools located near busy streets. B is the baseline indoor NO_2 exposure level in suburban schools in the winter season (14.9$\mu g/m^3$).

The final step is to quantify the number of additional asthma exacerbations attributable to indoor NO_2 concentration per primary school. This involves assessing the lower and upper estimates for Dc using the 95%CI for the adjusted OR.

2.2 Monetary valuation of the asthma exacerbations averted.

There are two main approaches to assigning economic values to health outcomes in the cost-benefit analysis of environmental health interventions: the human capital approach and the willingness to pay (WTP) approach(Bateman IJ. et al. 2002). The human capital approach quantifies the overall tangible cost to the society associated with a given disease. Despite the advantage of being straightforward and easy to compute, the human capital approach underestimates the real costs associated with diseases by not including intangible costs in the evaluation, such as the pain and the suffering associated with individuals' loss of well-being.

As the name suggests, the WTP approach involves eliciting how much individuals are willing to pay for a change in a health related risk (e.g. how much they are willing to pay for a 10% reduction in the risk of an asthma exacerbation). Since eliciting WTP directly from children is difficult, the majority of the WTP studies with respect to children's health have estimated the WTP using the "parental perspective"(OECD 2006). The parental perspective attempts to quantify how much parents are willing to pay to reduce the health risk faced by their children. According to Viscusi et al. and Alberini et al. the parental perspective offers a reliable source of WTP estimates because parents have defined preferences for their children's health and because parents are the persons who actually pay for their children's health risk reduction (Alberini A et al. 2010; Viscusi W.K. et al. 1987).

Nevertheless, according to the principle of consumer sovereignty the individuals who benefit from the health risk reductions are also the best judges to assign them an economic value(Dockins C et al. 2002). Also, if a parental perspective is adopted the WTP estimate is not based on children's preferences, and both parental altruism and parents' risk perception may bias WTP estimates (OECD 2006).

Only one study has elicited, using a contingent valuation questionnaire, WTP estimates for asthma health risk reduction from children (aged 7-19) and their parents (Guerriero C. et al.). The main findings of the study are that children have defined preferences for their own health risk reductions and that they are able to trade-off money for risk. The study also found that parental WTP values for risk reductions were significantly higher than the ones provided by children themselves.

As Pearce et al. suggest, the valuation of children's health risk depends on the household context and, in particular, on the distribution of the decision power within the household (Pearce D. et al. 2006). To the best of our knowledge, no study has explored the extent to which children's preferences for their own risk reduction are taken into account within the household. To account for the lack of information about the context of household decision making, this study uses three different WTP values to estimate the potential benefit of reducing indoor NO_2 exposure in primary schools: children's WTP adjusted for household budget, parents' WTP estimates and children's WTP given their monthly income. An aggregate household perspective (children plus parents WTP according to their personal budgets) was not adopted because of potential double counting.

The WTP values estimated in Guerriero et al. were adjusted to be used in the present study in two consecutive steps. Firstly, the statistical value of an asthma exacerbation was estimated by dividing the WTP estimate by the size of the risk reduction, Δr, associated with the policy (Pearce D. et al. 2006).

The second step consists in adjusting the value of an asthma exacerbation for the different context in which environmental policy is taking place. Since the WTP estimates for asthma risk reduction were estimated in Italy, they were translated into London values (2013 prices) using the unit value transfer with income adjustment procedure. The OECD recommends this method of benefit transfer because it is simple, transparent and generally yields reliable WTP estimates(Bateman IJ. et al. 2002; OECD 2011b). The formula used to translate the WTP for an asthma health risk reduction in the study site (Naples) to policy site (London) values is the following (Bateman IJ. et al. 2002; OECD 2011b):

$$WTP_J = WTP_i \left(\frac{y_j}{yi}\right)^e$$

Where WTP_i is the WTP estimate from the revealed preference study site, Y_i and Y_j are the income per capita in Naples and London respectively(ISTAT 2013; Statistic 2013). *e* is the income elasticity which measures the proportional change in WTP for the environmental health risk reduction in response to a proportional change in real income.

An income elasticity of 0.8 was assumed in the baseline analysis, as recommended by the OECD(OECD 2011b). Changes in the benefit estimates for different elasticity values were explored in one-way and in probabilistic sensitivity analyses. Yj, Yi and WTP values were converted to 2013 £ values using purchasing power parity adjusted exchange rate (OECD 2013). Given that the WTP study was conducted in 2013, adjustment of the WTP values was not necessary.

The resulting WTP per asthma exacerbation estimates were: £78, £93 and £4 assuming a child perspective adjusted for family budget, a parental perspective and a children's willingness to pay respectively(OECD 2006). The first and last WTP values adjusted for the age of child (younger children have a higher WTP compared to adolescents).

2.3 Time adjustment

The present value of the potential benefit (PVB) of reducing NO_2 indoor exposure in schools was estimated as follows:

$$PVB = \lambda * Dc * \frac{1}{(1+d)} * \left(1 - \frac{1}{(1+d)^t}\right)/d$$

Where: Dc is the number of asthma episodes that can be averted by reducing indoor NO_2 concentration in schools, t is the number of years over which the benefits accrue, d is the discount rate and λ is the willingness to pay for averting an asthma exacerbation (Guerriero C et al. 2011).

The time horizon considered in the baseline analysis is 10 years. One way sensitivity analyses have also been conducted for the purpose of assessing how a shorter (5 years) and a longer time frame (20 years) would affect the benefit estimates. The monetary value of future health benefits are discounted using a 3.5 % discount rate as recommended by the UK Treasury Green Book guidelines for economic evaluation(HM Treasury 2011).

2.4 Sensitivity Analysis

Sensitivity analyses were conducted in order to assess how the baseline estimates of the potential monetary benefits of reducing traffic-related asthma exacerbations changed according to changes in input parameters. Tornado diagrams were used to display the results of one way sensitivity analyses graphically for each of the three WTP perspectives.

The sensitivity analyses explored how the estimated benefits varied assuming a counterfactual concentration ranging from 40.2 mg/m^3, the lowest observed value observed in an urban school in the SINPHONIE study, and 49.4 mg/m^3 the highest value observed in the urban school located near a main traffic artery. According to Hammitt and Robinson, results of benefit transfers are sensitive to the value of income elasticity assumed in the model(Hammitt JK. and Robinson 2011). To assess how overall benefit varies by income elasticity, a range (0.04 to 1.00) similar to that of the US Environmental Protection Agency was used. A range which includes 0.4 the value suggested in the meta analysis by Lindhjem et al. which only included studies that satisfied the scope test (increasing WTP for higher risk reductions) (Lindhjem H. et al. 2011; OECD 2011a).

Univariate sensitivity analysis was also performed in order to assess how the prevalence of asthma and the I/O ratio affected the potential monetary benefits for reducing indoor NO_2 exposure in schools. The lowest estimate of asthma prevalence was 7.89%, which is the lowest prevalence found in the urban school children while the highest estimate, 12.50% was the prevalence of asthma among children in the urban school most exposed to traffic-related air pollution.

The estimate of the mean prevalence of asthma exacerbations among children with asthma assumed in the baseline analysis 10%, was retrieved from the Clean Air For Europe study and was assumed to be the same as the mean daily prevalence of bronchodilator usage among asthmatic children. One way sensitivity analysis was conducted in order to assess how the change in this parameter affects the estimates of the monetary benefits estimate of 2%, which is the prevalence of bronchodilator use among children living in Paris during the winter season and 13% which is the mean percentage using bronchodilators on any given day among asthmatic children living in Kubio (Finland) (Segala C. et al. 1998; Timonen KL and Pekkanen J 1997).

In order to assess how different discount rates affect study results, and also to allow comparison of the study findings with research using different discount factors, we present estimates of the potential benefit of reducing indoor NO_2 in primary school assuming a 2% discount rate as recommended by the European Commission in the guidelines for cost-benefit analysis and 7% discount rate, which is the discount rate estimated by Alberini et al. as best reflecting individuals' preference for future mortality risk reduction associated with remediation of contaminated site(Alberini A. et al. 2007; EC 2001). It is difficult to establish the duration of the health benefit arising from pollution control interventions a priori. In the baseline analysis, the reduction of NO_2 indoor exposure was assumed to last for 10 years. To assess how potential benefits might increase/decrease according to different time frames, we performed a one way sensitivity analysis assuming a time horizon of 2 years and of 20 years.

A Monte Carlo simulation with 1,000 iterations was also performed to assess how parameter uncertainty affects the model results. Probability distributions were assigned to the main parameters in the analysis according to standard guidelines for economic evaluation of health care intervention(Briggs et al. 2008). A Gamma distribution was assigned to willingness to pay estimates, Beta distribution was adopted for probability estimates (e.g. baseline asthma prevalence, daily probability of bronchodilator use) and a uniform distribution was assigned to outdoor NO_2 measures and number of days per year in which pupils are exposed to high indoor NO_2 concentrations.

3. Results

Reducing indoor NO_2 exposure in a London primary school would result in a reduction of 82 asthma exacerbations each year (30-141 asthma exacerbation per year)(Table 2). Table 3 reports the potential monetary benefit per school associated with indoor NO_2 exposure at school assuming a 10 year time horizon for the pollutant reduction and 3.5% discount rate. According to the different WTP estimates adopted for the analysis, the total monetary benefit ranges between: £2.5k per school if a child perspective (considering child's budget) is used up to £60k if the parents' perspective is adopted. The last row of Table 3 also reports the benefit per pupil which has been estimated by dividing the overall monetary benefit by the average number of students in the SINPHONIE sample.

Results of the sensitivity analyses are reported in the tornado diagrams in Figure 1. The uncertainty is expressed as the change from baseline estimates (black vertical line) of the monetary benefit of reducing NO_2 exposure.

Assumption about the duration of the benefits and the daily probability of having an asthma exacerbation have the greatest impact on the monetary benefit associated with the reduction of NO_2 exposure. If the daily probability of having an asthma exacerbation is 2% the potential benefit assuming a parents' perspective is £12K while if the daily probability is 13% the potential benefit is almost £78K.

The third most influential source of uncertainty is the I/O ratio. Assuming an I/O ratio of 0.6 the potential benefit from a children perspective adjusted for household budget is £35k. Alternatively, if the I/O ratio is equal to 0.8, then the potential benefit increases to approximately £63K. As expected, by holding the other parameters constant, the potential benefit achievable by reducing indoor NO_2 concentration was also found to be sensitive to the I/O ratio and to the baseline asthma prevalence.

Results of 1,000 iterations of Monte Carlo simulation suggest that the average monetary benefits is £44,304 (95%CI: 1,736-182,727), £53,135 (95%CI: 2,089- 206,999) and £2,196 (95%CI: 195-9,203) assuming a children's perspective adjusted for household budget, a parents' perspective and children's WTP estimate respectively.

4. Discussion

This study is the first to quantify the potential benefit of preventing traffic-related childhood asthma exacerbations in children attending primary schools using indoor air quality data. The results suggest that there are approximately 82 asthma exacerbations that can be prevented by reducing outdoor NO_2 concentrations each year in a primary school located in proximity to busy roads. The associated potential monetary benefit of reducing indoor NO_2 exposure during school time, depending on the perspective adopted for the analysis, would range between £2.500 and £60k per school. The results of the deterministic sensitivity analysis suggest that the duration of the benefits and the daily probability of having an asthma exacerbation are the most influential parameters in the analysis.

According to the latest estimates provided by Transport for London, there are 1,148 schools within 150 metres and 2,270 schools within 400 metres of roads in London carrying over 10,000 vehicles per day (Clean Air in London 2011). Assuming that 60% of these schools are primary schools, there is a considerable number of asthma exacerbations due to NO_2 exposure that can be prevented in children at primary schools in London each year.

Two main strategies can be adopted in order to mitigate indoor pollution levels in school classrooms: (a) filtration of outdoor air or (b) reduction of the source. Filtration strategies have many disadvantages including increased energy consumption of the school building stock, reduced efficiency of removal, and more importantly, in cases of poor maintenance of the mechanical systems, further deterioration of indoor air quality (Wargocki P. et al. 2002).

Reduction of outdoor sources seems therefore preferred and may include greening of urban spaces and introduction of traffic-free zones around schools (Perez et al. 2012). It is difficult to identify a priori cost-effective strategies to reduce traffic pollution in the London area. According to Tonne et al., the congestion charge scheme, which, implemented in February 2003, is one of the world's most ambitious traffic congestion schemes, had only a modest effect on NO_2 concentrations and its effects were mainly localised in the congestion charge zones (Tonne C. et al. 2008). Mediavilla-Sahgun and Simon estimated the effect of different interventions to reduce traffic-related emission. For example, they suggest that the adoption of low emission fuels for vehicles or the use of electric buses for public transportation may substantially decrease air pollution in London in the next few years (Mediavilla-Sahagun A. and Simon A.P. 2006). The study conducted by Woodcock et al. estimated that the benefits arising from a decreased use of motor vehicles in London through the promotion of walking and cycling would be associated with higher health benefits (7332 disability adjusted years of life in one year) than those arising from an increased use of lower emissions vehicles (160 disability adjusted years of life in one year)(Wookcock et al. 2009).

Indicative results of the monitoring investigation suggested that increased airtightness of the building envelope and ventilation strategies may reduce permeability of NO_2 and protect occupants from this harmful pollutant. Although, more research is necessary, if the building envelope can filter outdoor NO_2, there would be an even greater incentive to build low carbon emission buildings as these would both reduce greenhouse-gas emissions and reduce NO_2 indoor exposure (Chatzidiakou 2014).

When interpreting the study findings, several limitations also need to be considered. Firstly, NO_2 levels over the academic year were taken from the fixed monitoring network rather than from the immediate school premises, where concentrations may be different. To account for this discrepancy, we compared passive sampling measurements taken in the school premises with measurements from the fixed monitoring station, and found a good agreement. Because readings in the fixed monitoring station were higher than readings in the immediate school microenvironment, we corrected this discrepancy by using a higher threshold value for the outdoor measurements, which would correspond to indoor NO_2 levels of 40 μg/m3.

The generalisability of this study is limited, as the sample size and the age group considered is small. The analysis was conducted using the OR estimated in the SINPHONIE study among children aged 9 to 11 years also for younger children attending primary school. Future studies are necessary to determine whether there is an effect of NO_2 for younger children (below 9 years). Additional studies are needed to estimate the relationship between air traffic pollution exposure at school and asthma exacerbation (and possibly asthma onset) characterised by high NO_2 outdoor concentrations and high childhood asthma prevalence in urban areas such as London. Further limitations in interpreting the findings, include the lack of personal exposure assessment and the challenge of separating school exposure from other exposures, as children attending urban schools may be living in proximity to the school, and therefore be exposed to high levels of traffic-related pollutants at home. The association between NO_2 exposure with asthma exacerbations are consistent with current epidemiological evidence that points towards a causal link (Kelly F.J. and Fussel J.C. 2011). Finally, as there was a significant difference between indications of deprivation in the investigated schools, exposure to NO_2 may reflect a broader picture of inequalities in health, as children from poorer households tend to have worse health outcomes(UK) ((WHO) 2013).

Previous studies quantifying the health impact of PM_{10} on asthma exacerbation in children suggest that the bronchodilator usage among those that are asthmatic is a reliable measure of the exacerbations of asthma(Just J. et al. 2002; Martuzzi M. et al. 2006). However, bronchodilator usage may overestimate the number of asthma exacerbations it is difficult to identify which factors trigger the use of bronchodilator in children. It may be possible that, for example, those children not having an asthma exacerbation but having asthmatic symptoms such as coughing and feeling wheezy use their bronchodilator. On the other hand, the study estimate of the potential benefit achievable by reducing indoor NO_2 exposure in primary school children in London considered only asthma exacerbations and not their potential consequences. The consequence of a asthma exacerbation for children may have a severe and long-lasting impact on children quality of life, parents' life and health care resource use (Brandt et al. 2012). In addition, there is mounting evidence that traffic-related exposure is also associated with childhood neurodevelopmental outcomes (Guxens M. et al. 2012). Consequently, the study may significantly undervalue the potential burden of other health outcomes that can be prevented by improving indoor air quality in classrooms.

Most cost-benefit analyses value the health benefits to children using cost of illness values or adults' WTP estimates (OECD 2005). This study estimates the potential benefit of reducing NO_2 exposure using for the first time both parental and child perspectives. Despite the advantage of taking into account child preferences for health risk reduction, one possible limitation of the study is that the WTP estimates came from a study conducted in Italy and translated to London values using the benefit transfer procedure. Potential transfer error due to differences in real prices and incomes between countries, differences in attributes of the users and in cultural and context characteristics may have influenced the study results (OECD 2011a). Studies examining the validity of the benefit transfer approach found that the methods used (e.g. currency conversion only, income adjustment and value function approach) to translate WTP values between sites may significantly affect the transfer error (estimated to be in the range between 20% and 40%)(Ready R. and Navrud S. 2006). The present study tried to minimize the transfer error by using purchasing power parities and accounting for income differences between the study and the policy sites. The study also adjusted the WTP values to account for population characteristics (age of children who would benefit from NO_2 reduction)(OECD 2011a). Additional willingness to pay studies need to be carried out in the UK, and possibly in different regions, to assess how much schoolchildren and their parents are willing to pay to reduce asthma related risk.

This study focuses only on a small part (childhood asthma) of the potential burden of disease avoidable by reducing traffic exposure pollution among school children. Nevertheless, this study suggests that there is a strong economic incentive for providing a healthier indoor class environment by reducing the traffic pollution close to schools.

5. Conclusion

Given the increasing demand for primary school places, the UK Government announced £1.6 billion of funding for new school places last year, with London receiving more than a third of this funding, £576 million (Department for Education 2013). In addition to the rapidly growing English population and the demand for new schools, retrofitting and maintenance is necessary because of the great age and many years of intensive use of the current building stock. All the above factors indicate the urgent and increasing demand for design and retrofitting guidelines for healthy school buildings. Given the strong association between traffic-related exposure in the school with high prevalence of asthma and asthmatic symptoms, It was shown, both from the school sample and the literature that urban schools should be located at least 400 m away from main traffic arteries(Appatova A.S. et al. 2008). Designers, engineers, policymakers and stakeholders need to consider the high spatial variability of outdoor pollution levels in urban locations before selecting sites for new school buildings. Such consideration prior to construction may involve extensive monitoring efforts of external air quality in proximity to a proposed school site, or collaboration with the local council to introduce greening or pedestrianisation schemes.

More, broadly, this paper highlights that there is a strong economic incentive to direct policy towards city-wide planning to decrease outdoor pollution levels, which would improve the health of the students and reduce the prevalence of respiratory illness in childhood,

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Supplementary Material

The UK database of the SINPHONIE project

Overall, 38 environmental and health institutions from 25 countries participated in the SINPHONIE study. The study adopted a multidisciplinary approach creating an integrated database of (a) physical, chemical and microbiological levels in classrooms, (b) building characteristics, meteorological parameters and the microenvironment and (c) health responses collected with a standardised field survey matched with non-invasive clinical tests. The UK database of the SINPHONIE project was used as the basis for the health-based monetary evaluation of reducing air pollution in UK schools presented in this study.

Case Studies

Consistent with the harmonised SINPHONIE methodology, a detailed investigation was conducted in five state-run primary schools in Greater London from October 2011 to January 2012. The fieldwork was repeated in the non-heating season (March-June of 2012). The sample comprised three schools built in the 19th century (Victorian) in central London, and two contemporary schools in suburban areas. The schools (S1-S5, see Table 1) varied considerably in terms of their construction characteristics and proximity to likely external pollution sources. The Victorian urban schools are high thermal mass buildings with un-insulated walls, while the suburban schools are contemporary buildings with a mixture of insulated walls of high and low thermal mass. S2 was designed as a low-carbon building, with high air-tightness and good thermal performance. Urban school S3 was located in immediate proximity (<150m) to a main street with high traffic intensity, while urban S4 and S5 were surrounded by pedestrian streets and vegetation (urban background) 150m to 300 m away from main traffic arteries. Traffic in S2 was related to the operation of the school, and coincided with the start and the end of the occupied period. S1 was located in a residential area about 400m away from a high traffic street. A detailed description of the case studies, methodology used for monitoring of the pollutants and main results are presented in (Chatzidiakou, 2014, Chatzidiakou et al., 2014).

Table 1. Construction characteristics of the investigated schools

School	Area	Investigation period	Construction Year	Free School Meals	Ventilation Strategy
S1*	Suburban	9 January 2012- 13 Jan 2012	2000	37%	NV cross-ventilation with windows on high level
S2	Suburban	14 Nov 2011- 18 Nov 2011	2010	22%	MM NV Assisted with Mechanical Exhaust
S3	Urban in immediate proximity to main traffic artery	21 Nov 2011- 25 Nov 2011	1896	53%	NV single sided
S4	Urban background	28 Nov 2011- 2 Dec 2011	1870	13%	NV single sided
S5	Urban background in proximity to a carpentry industry	5 Dec 2011- 9 Dec 2011	1866	95%	NV single sided Restricted windows in winter

NV: Natural Ventilation ;MV: Mechanical Ventilation;*S1 in this paper corresponds to S6 in papers (Chatzidiakou, 2014, Chatzidiakou et al., 2014)

Monitoring was performed over five typical consecutive teaching days in three classrooms and one outdoor site in each school. Selected classrooms had comparable occupancy densities and schedules, and were occupied by older children (9-11 years old). Socioeconomic information collected included percentage of students eligible for Free School Meals (FSM), which is a crude financial indicator long used as the main indicator of deprivation in official estimates, together with UK educational research reports (Croxford, 2000). The high percentage of Free School Meals (FSM) reported in S5 (Table 1) was related to a school policy offering FSM to all students regardless income through an independent supplier.

Environmental parameters

Outdoor NO_2 concentrations are significantly higher during the winter season due to complex meteorological and photochemical phenomena (Gallois D. et al., 2005); therefore measurements were performed from November to January (Table 1) with passive samplers exposed for a period of two weeks. See paper for details? Readings from the nearest central station (Islington Upper Street) ranged from 58.0 to 62.8 μg/m^3, and were in good agreement with concentrations sampled in urban school premises that ranged from 40.2 to 49.4 μg/m^3 (Table 2). Among the urban schools, the highest concentrations were recorded in S3, which was located in immediate proximity to a high traffic intensity street. The strong spatial variation of outdoor NO_2 concentrations was reflected in the two-fold higher concentrations recorded in urban school premises compared with suburban schools which ranged from 28.0 to 30.2 μg/m^3 (mean: 29.1 μg/m^3, σ: 1.1), and the difference was statistically significant ($p>0.001$).

Table 2. Indoor and outdoor NO_2 concentrations (μg/m^3) in the study schools during the heating season using passive sampling

	Indoor mean (σ)	**min-max**	**Outdoor (σ)**	**Outdoor Central Station**	**I/O ratio**
S1*	21.6 (0.9)	20.4 - 22.5	30.2		0.7
S2	10.9 (2.2)	9.1 - 13.6	28.0		0.3 - 0.5
Suburban	**14.9 (5.6)**	**9.1 - 22.5**	**29.1 (1.1)**		**0.5 (0.2)**
S3	37.9 (2.4)	35.6 - 41.2	49.4	58.0	0.7 - 0.8
S4	27.6 (1.9)	25.5 - 30.0	40.2	61.0	0.6 - 0.8
S5	28.0 (2.8)	26.0 - 31.9	41.5	62.8	0.6 - 0.8
Urban	**31.2 (5.3)**	**25.5 - 41.2**	**43.7 (4.1)**	**60.6 (2.0)**	**0.7 (0.1)**
Total	25.2 (9.1)	9.1 - 41.2	37.9 (7.8)	.	0.6 (0.2)

σ: standard deviation, *S1 in this paper corresponds to S6 in papers (Chatzidiakou et al., 2013b) and (Chatzidiakou et al., 2013a)

In the absence of indoor sources, indoor NO_2 is strongly influenced by outdoor levels, and is usually below ambient levels due to chemical reactions and deposition on internal surfaces. Affected by outdoor concentrations, indoor concentrations in the suburban schools were in the range from 9.1 to 22.5 μg/m^3 (mean: 14.9 μg/m^3, σ: 5.6), half ($p>0.001$) the indoor levels in urban schools which ranged from 25.5 to 41.2 μg/m^3 (mean: 31.2 μg/m^3, σ: 5.3).

The simplest screening method for calculating long term indoor concentrations from outdoor sources is the indoor to outdoor (I/O) ratio, which is widely used in epidemiological studies. Currently, there is limited evidence on the effect of envelope air-tightness on penetration ability of NO_2; however, results indicated that airtight S2 had lower I/O ratios ranging from 0.3 to 0.5 compared with I/O ratios calculated in the rest of the schools (0.6 to 0.8). Previous investigations in school buildings reported even higher I/O ratios 0.8<I/O<1.2(HESE, 2006, Poupard O., 2005, Blondeau P. et al., 2005).

Asthma prevalence in relation to NO_2 exposure in London

Information on prevalence of asthma and asthmatic symptoms in children in the school environment was collected through an on-site questionnaire survey. The same questionnaire survey was administered in the non-heating season (follow-up) to capture the incidence of asthma attacks and asthmatic symptoms in the school environment. In total, 376 students of 432 (Response Rate: 87%) participated in the baseline and follow-up study. Of these, 50.7 % were girls, and the average age was 10 years (range: 9 to 11). In total, 131 students attended two suburban schools, and 245 attended three urban Victorian Schools. Asthma prevalence in suburban schools was 1.54% and was almost seven times lower than the 10.16% in urban schools (range: 7.89% to 12.50%). The highest number of asthmatic children in the school environment was recorded in S3 which was close to a busy street with the highest NO_2 levels (Table 3). Findings were consistent with The International Study on Asthma and Allergies in Childhood (ISAAC) results, which show that the prevalence of asthma among children in primary schools in UK is 7.18%, which is the highest among European Countries (Mallol et al., 2013).

Table 3. Prevalence of asthma in the SINPHONIE study

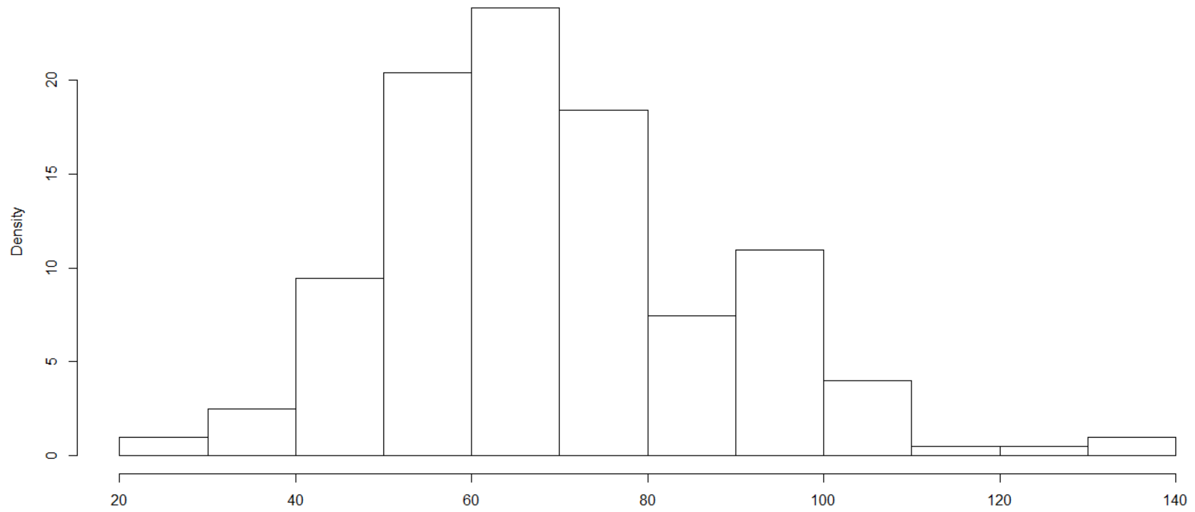
	Prevalence (%)
S1*	1.49
S2	1.59
SINPHONIE: Suburban	**1.54**
S3	12.50
S4	7.89
S5	9.76
SINPHONIE: Urban	**10.16**
SINPHONIE: Total	**7.18**

Among all investigated pollutants, multilevel logistic regression (at classroom and pupil level) controlling for the effect of the school, gender, age and exposure to environmental tobacco smoke at home, revealed that only exposure to outdoor concentrations of NO_2 (and thus indoor NO_2 concentrations) was significantly related to asthma prevalence in the school environment. Exposure to indoor NO_2 (OR: 1.11, 95% CI: 1.04-1.19) in the school environment was positively associated with prevalence of asthma and asthmatic symptoms in the school environment (Chatzidiakou et al., 2015).

The strength of that association falls within the range estimated in a systematic meta-analysis of 19 studies between exposure to NO_2 with prevalence of asthma (meta-OR: 1.05, 95% CI: 1.00–1.11) (Gasana J. et al., 2012)

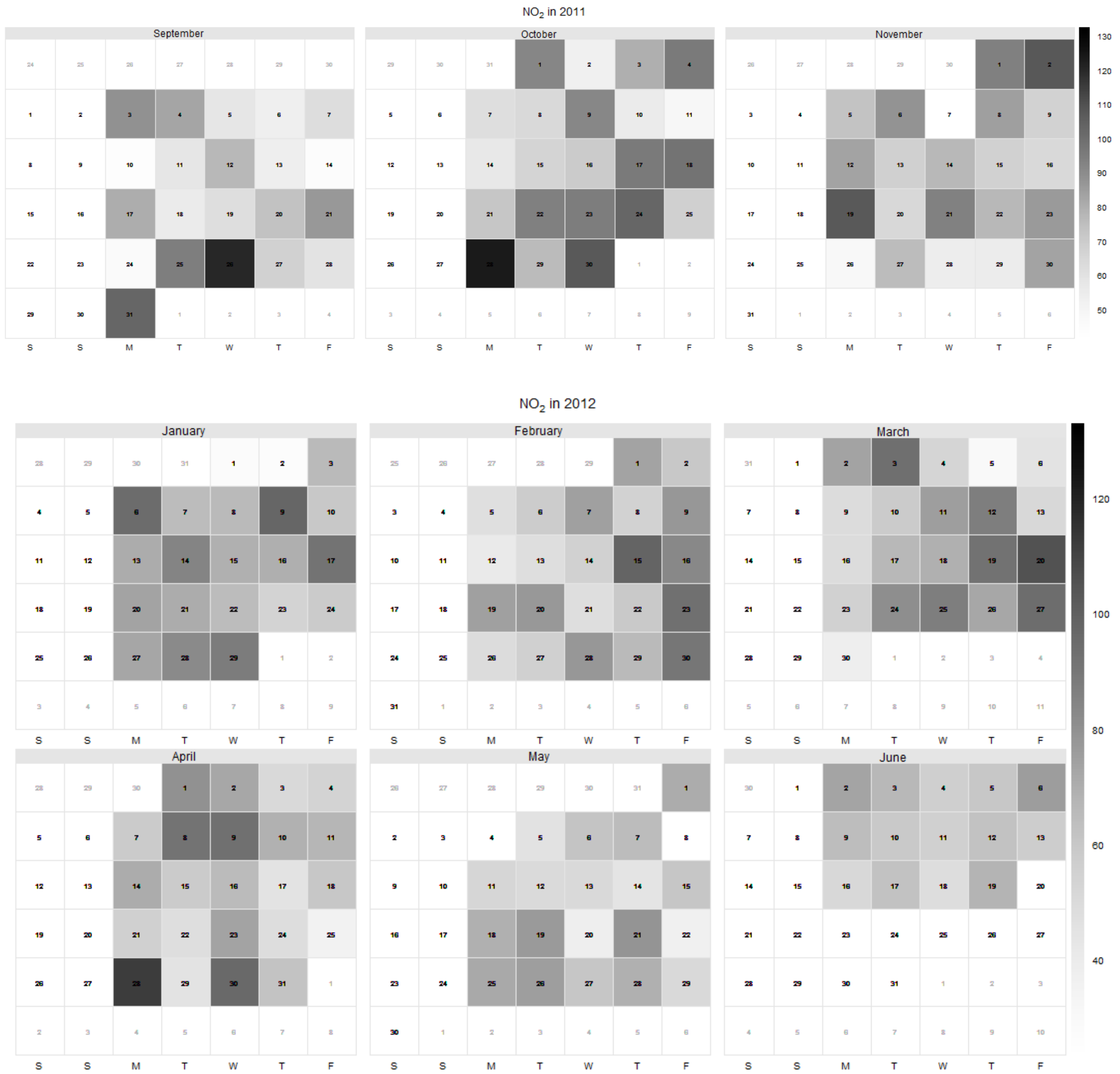
No incidence of asthma attacks or asthmatic symptoms in the school environment was reported in the non-heating season (Chatzidiakou et al., 2015b).

Figure 1: daily mean NO2 levels (µg/m3) monitored in a fixed monitoring station (urban background) in proximity to the schools



Data: http://www.londonair.org.uk/LondonAir/Default.aspx

Figure 2: Daily mean outdoor NO_2 levels monitored in a fixed monitoring station in an urban background location in proximity to the schools.



Figure
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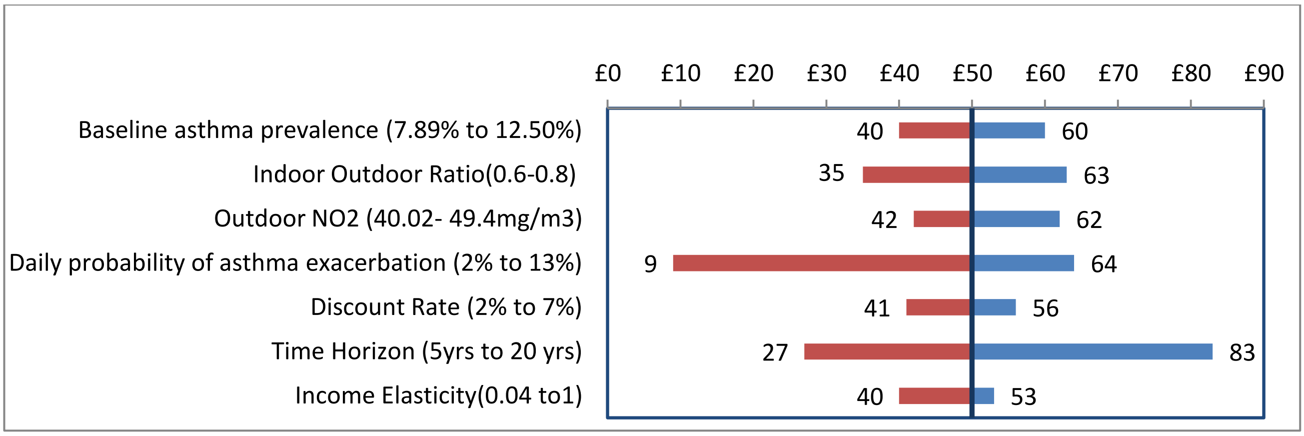
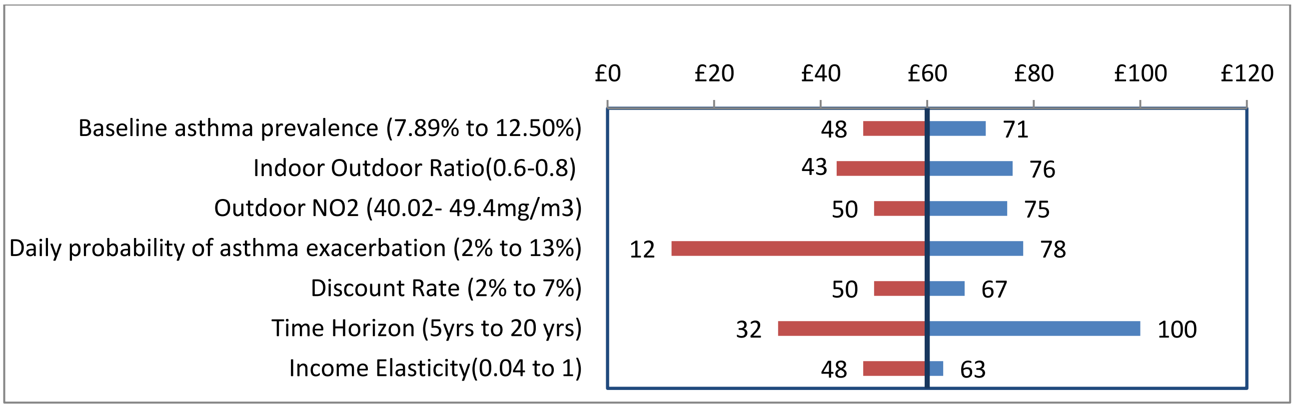
Figure 1. Tornado Diagram showing sensitivity analysis results.

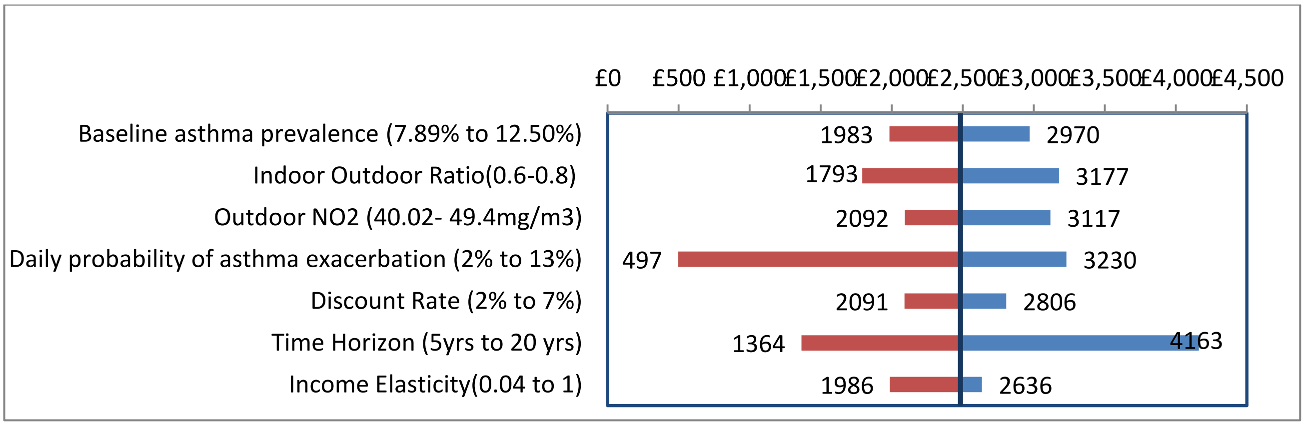
Children's perspective adjusted for family budget (values in thousand £).



Parents' perspective (values in thousand £).



Children's perspective (values in £).



Table
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Table 1. SINPHONIE study London Sample.

School	Area	Construction Year	Indoor NO_2 mean (SD) µg/m3	min-max µg/m3	Outdoor NO_2 (SD) µg/m3	Outdoor NO_2 Central Station µg/m3	I/O ratio	Asthma Prevalence (%)
S1*	Suburban	2000	21.6 (0.9)	20.4 - 22.5	30.2		0.7	1.49
S2	Suburban	2010	10.9 (2.2)	9.1 - 13.6	28.0		0.3 - 0.5	1.59
Suburban			**14.9 (5.6)**	**9.1 - 22.5**	**29.1 (1.1)**		**0.5 (0.2)**	**1.54**
S3	Urban in immediate proximity to main traffic artery	1896	37.9 (2.4)	35.6 - 41.2	49.4	58.0	0.7 - 0.8	12.50
S4	Urban background	1870	27.6 (1.9)	25.5 - 30.0	40.2	61.0	0.6 - 0.8	7.89
S5	Urban background in proximity to a carpentry industry	1866	28.0 (2.8)	26.0 - 31.9	41.5	62.8	0.6 - 0.8	9.76
Urban			**31.2 (5.3)**	**25.5 - 41.2**	**43.7 (4.1)**	**60.6 (2.0)**	**0.7 (0.1)**	**10.16**

NV: Natural Ventilation ;MV: Mechanical Ventilation ;SD: standard Deviation*S1 in this paper corresponds to S6 in papers (Chatzidiakou et al. 2014; Chatzidiakou 2014) (Chatzidiakou et al. 2013b) and (Chatzidiakou et al. 2013a)

Table 2. Annual Asthma Exacerbations associated with high indoor NO2 exposure per school.

Overall number of asthma exacerbations OR (95%CI)	Asthma Exacerbations per pupil OR (95%CI)
82 (30-141)	0.2 (0.1-0.4)

OR: Odds Ratio; CI: Confidence Interval

Table 3. Monetary Benefits of reducing NO_2 exposure per school assuming 10 year horizon.

	Children's preferences adjusted for family budget	Parents' preferences	Children's preferences
Overall Monetary benefit	£49,783 (£18,231-£85,304)	£59,740 (£21,878-£102,365)	£2,485 (£910-£4,258)
Benefit per pupil[a]	£120 (£35-£162)	£144 (£53-£246)	£6 (£2-£10)

a: Overall Monetary Benefits divided by mean number of pupils in the primary school