Dirty Money: Is there a Wage Premium for Working in a Pollution Intensive Job?

Matthew A. Cole*

Robert J. R. Elliott*

Joanne K. Lindley**

Abstract:

Within a compensating wage differential framework we investigate whether there is a wage premium for working in a pollution intensive industry Our results for the economy as a whole suggest that there is a small wage premium of approximately one half of one percent associated with the risk of working in a dirty job. The premium rises to approximately ten percent for those individuals who work in one of the ten dirtiest industries. There is also some evidence that existing levels of pollution affect the size of the pollution exposure-wage elasticity that is suggestive of a threshold type effect of pollution on wages.

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* Department of Economics, University of Birmingham, Edgbaston, Birmingham, B15 2TT, UK.
** Department of Economics, University of Sheffield, 9 Mappin Street, Sheffield, S10 2TN, UK..
Corresponding author: Robert Elliott, Department of Economics, University of Birmingham, Edgbaston, Birmingham, B15 2TT, UK. r.j.elliott@bham.ac.uk. Tel: (44) 0121 4147700

1. Introduction

The existence of compensating wage differentials harks back to Adam Smith and is the fundamental model of long-run labour market equilibrium. The basic premise is that any two jobs are likely to differ in numerous ways: location; working environment; hours of work; fringe benefits; promotion opportunities; safety etc. If knowledge of work hazards is complete, and workers are sufficiently mobile, then the market will ensure that workers are fully compensated for the increased risk that they face (see for example Duncan and Holmlund 1983 and Elliott and Sandy 1998). A number of studies have attempted to identify the degree of compensation that workers receive as a result of increased risk, an approach which yields estimates of the value of a statistical life (VSL).[1]

In this paper we address a related issue that has not previously been considered within the compensating wage differential literature and ask whether there is a wage premium for working in a dirty job. We define 'dirty' as a working environment that has a high level of exposure to chemicals or pollutants that may, in turn, have a detrimental effect on an individual's health. If there is an unknown but positive probability that an individual will suffer a long or short-term illness, or possibly death, from working in a dirty industry then taking such a job can be considered a form of risk-taking behaviour by the individual. As such, it should therefore be possible to calculate wage premia using a hedonic wage methodology.

The theoretical case for wage compensation for working in a dirty job is based on the standard hedonic wage equilibrium model. It can be argued that workers will receive wage premia that exactly offset the disutility of working in a pollution intensive job

[1] Most VSL studies centre on one basic premise: that the VSL should roughly correspond to the value that people place on their lives in private decisions. The VSL literature usually estimates VSLs using measures of fatal and nonfatal risk. See Viscusi (1993), Dorman and Hagstrom (1998) and Viscusi and Aldy (2003) for a review of the existing literature and Mrozek and Taylor (1999) for the results of an often cited meta-analysis on the determinants of the value of life. Mrozek and Taylor (1999) offer a best practice estimate of VSL of $2million (1998 prices), for people facing risks around 1 in 10,000. They report four specifications that provide estimated elasticities of VSL with respect to wage of 0.50 to 0.88 with standard errors of 0.26 and above. The Mrozek and Taylor (1999) VSL estimates come from 33 labour market studies controlling for average wage, risk and other factors. Note that their estimates are considerably less than the Environmental Protection Agency (EPA) VSL figure of $6 million (1998 dollars). Burtraw *et al*. (1998), Hagler-Bailly (1995) and USEPA (1997) all show that the benefits far outweigh the abatement costs even if VSL figures were to be reduced by two thirds.

under the following assumptions: workers are fully informed of the risks of working in a dirty job; they have utility functions where the expected likelihood and costs of exposure to harmful emissions and other occupational hazards enter as arguments; if firms possess information on workers' preferences and expectations; if a pollution-free working environment is costly to provide; and labour markets are perfectly competitive. If any of these conditions fail to fully apply then the actual compensation may be less than utility offsetting, nonexistent or even negative (Dorman and Hagstrom 1998). Therefore, whether pollution exposure will result in a compensating wage differential is essentially an empirical question.[2]

The contribution of this paper is to provide the first estimates of the wage premia associated with pollution risk using disaggregated industry level pollution data. In addition we investigate whether there is a compensating wage differential for working in an industry with a high level of workplace injury. We undertake our analysis at the individual level since a failure to control for unobserved heterogeneity in the determinants of industry level wages can impart an upward bias on the wage premium for risk**.** To ensure that our estimates of pollution risk and nonfatal risk premia are accurate, we control for as many of the causes of inter-industry wage differentials as possible by including a carefully selected set of industry level variables and a full set of disaggregated industry and broad occupational dummies. We also control for a wide range of individual characteristics believed to be determinants of wage levels.

Our main finding is the existence of a positive and significant wage premium attached to working in a dirty industry, across a range of pollution exposure measures. The average premium across all industries is found to be approximately 0.5% percent of the weekly wage but a premium of approximately 10% is found for individuals employed in one of the ten dirtiest industries. This relationship is robust to numerous sensitivity checks. There is also a suggestion that an industry's absolute level of emissions plays a role in wage premium determination as wage-pollution exposure elasticities differ across industries perhaps suggesting a non-linear or threshold type effect. A secondary result is that we find a statistically insignificant compensating wage differential for nonfatal risk. Although this contradicts the results of many early

[2] A lively debate on the existence of wage compensation continues. See Dorman (1996) for a broader discussion of these assumptions and theoretical reasons for doubting their applicability.

studies, it supports the evidence found in those wage-risk studies that use more appropriate econometric specifications (see e.g. Leigh 1993 and Bellman 1994).

The remainder of this paper is organised as follows: Section 2 pieces together the relevant literature from the wage-risk, inter-industry wage differential and pollution-health literatures; Section 3 outlines our methodology and describes our data; Section 4 presents our results while Section 5 concludes.

2. Review of the Literature

There has been little written on the impact of industrial pollution on wages. In this section we discuss the relationship between wages, job risk and pollution and how these relationships have so far been considered in the literature. First we consider the relationship between VSL estimates and the environment and the factors that may hinder the estimation of pollution related wage-premia. Second, we discuss pollution risk within the context of the inter-industry wage differential literature before briefly discussing how pollution can affect an individual's health and thus the riskiness of working in a given industry.[3]

2.1 Obstacles to the Estimation of 'Dirty' Wage Premia

At the individual level, the literature is less developed although there is a small literature that discusses the factors that might influence an individual's perceived pollution risk and hence the likelihood that an individual would demand a wage premium. There are three primary considerations.

[3] There have been a limited number of studies that have examined the impact of environmental regulations on employment although they generally find little effect. For the US, studies by Morgenstern *et al*. (2002) and Berman and Bui (2001) find no evidence to suggest that regulations have adversely affected industrial employment with the former actually finding weak evidence that regulations may result in a small net increase in employment. However, studies by Henderson (1996), Kahn (1997) and Greenstone (2002), again for the US, indicate that industries located in counties with stringent regulations have experienced job losses, or at the very least lower employment growth rates, relative to industries in less regulated counties. Cole and Elliott (2006) provide a recent UK study with some evidence that regulations do cause job losses.

First, a general lack of knowledge by the public and employers on the impacts of pollution on health and disease may undermine the market's ability to generate compensating wage differentials for the effects of pollution on health. Shilling and Brackbill (1979) estimate that only about 5% of workers were fully informed on the job hazards of their occupations.[4] In a related study, Brown (1987) interviewed workers in dangerous chemical plants and concluded that workers employ a psychological defence mechanism of denial by refusing to believe that the probability of death or serious injury is high.[5]

A second consideration is that health problems (or indeed nonfatal injuries) may be compensated *ex-post*. Hence dirty or risky jobs have to be only partly compensated *ex-ante* through higher wages due to the presence of worker compensation benefits that may be written into a worker's contract.

Third, it can be argued that individuals' perceptions of pollution or nonfatal risk are heterogenous so, for example, ethnic minorities and those from lower socio-economics backgrounds may have different perceptions of risk or at least be less mobile and hence have fewer alternative employment options (Viscusi 2003). Leeth and Ruser (2003) include sex and ethnic dummies to address Viscusi's (1993) point on possible risk preference differences across sex and ethnicity. It is also possible that wage premia will differ with age as older workers, with a shorter discounted expected future, are risking less of their life.[6]

[4] Although a significant amount of information is available on the effects on health of asbestos, vinyl cloride, coke emissions, benzene, arsenic, cotton dust, acrylonitrile, lead and ethylene oxide, not a great deal is known about whether the many chemicals that workers are exposed to at work are cancer-causing and whether or not threshold effects exist. A scientific literature is emerging on the long-term effects of chemicals, but as many of the effects may take many years to become apparent, and since it might be combinations of chemicals that result in synergistic effects, considerable difficulties arise in locating carcinogens (Kostiuk 1990).

[5] This is less of a concern in this paper, as we are not using self-reported risk measures.

[6] Leeth and Ruser (2003) find, in a study for the US, that both workplace fatalities and injuries are higher for men than women and for blacks and Hispanics than for whites and other minorities. Variation in risk preference among groups, perhaps caused by income, family background or social norms may produce differences in risk. However, once the occupational distribution of workers is accounted for they find there is no premium for males but they do find that men and women in blue-collar jobs earn a premium but that no premium exists for white-collar jobs. Viscusi (2003) also reveals, in a US study, that blacks do face a higher fatality risk and nonfatal injury-risk but that the differences are not that great. Viscusi (2003) also shows that black employees do receive significant premiums for nonfatal risks so it seems that there is evidence of constructive market performance on behalf of black employees. The problem, however, is that although black employees undertake greater risk than whites, they also receive lower annual pay. Viscusi (2003) states that "…there must be

Related to the third point is the ongoing theoretical controversy linked to unobservable worker heterogeneity and VSL estimates. One recognised problem with all wage-risk studies is issue of endogeneity, as raised by Garen (1988). The concern is that the behaviour and habits of individuals could lead to self-selection that affects estimates of compensating wage differentials. It is possible that those workers with the greatest earnings capacity are likely to choose safer and less pollution intensive working environments (assuming safety and pollution-free working conditions are normal goods). Thus, individuals with the greatest human capital and highest earnings potential will experience an income effect and therefore select safer and cleaner jobs.[7] Other than the wage, there may also be unobserved heterogeneity that influences job risk. If individuals differ systematically in unobserved characteristics that affect their productivity and earnings, in dangerous jobs these will also affect their choice of job risk (however measured).[8]

After attempting to control for these endogenity issues, Garen (1988) finds generally larger VSL estimates and suggests that the behaviour of workers may have considerable influence on the level of fatality rates in hazardous jobs. However, as Kostiuk (1990) points out, Garen's (1988) methodology, removes unobserved worker heterogeneity as an influence on the estimates. This is fine if the unobserved heterogeneity is the behaviour of workers in the face of risk alone. However, differing risk parameters across workers are a necessary condition for the market to generate compensating wage differentials unless we assume all individuals' indifference curves are identical. The Garen technique therefore removes too much.[9]

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fundamental differences in labor market opportunities for blacks and whites as well as the structure of their offers for risky jobs" pg. 254. For non-fatal injuries, that is more closely aligned with our study, both men and women earn a wage differential but this figure is three times larger for women. Leeth and Ruser (2003) also show that white women earn the highest wage compensation for non-fatal risk. Black, Hispanic and other minorities also receive higher pay for bearing nonfatal injury risk but the premiums were smaller than for white women.

[7] If the disturbances reflect unobserved individual heterogeneity and there is a correlation between the disturbances that influence wage determination and those that affect job risk, then those with the unobserved characteristics will earn higher wages and choose a safer job. This will bias OLS results.

[8] This implies cross-equation correlation of disturbances in the wage and risk equations using OLS and will bias the estimates.

[9] We attempted to employ the Garen methodology to control for the possible endogenity of our nonfatal and pollution risk variables. The coefficient on nonfatal risk did not alter significantly and remained insignificant and had little impact on the pollution risk coefficient. We were unable to instrument for possible endogeneity between wages and pollution intensity as no suitable instruments were available. Results when nonfatal risk is instrumented are available from the authors upon request.

A more recent argument, related to Garen (1988), hinges on the relationship between unobserved general productivity and safety specific productivity. Hwang *et al*. (1992) argue that VSL estimates are underestimates as econometric analysis only partially observes worker characteristics and cannot observe general productivity. However, Shogren and Stamland (2002) argue that VSL estimates may be biased upwards if they do not take into account the differing abilities of workers to cope privately with job risk or what Shogren and Stamland (2002) pp. 1169 call "…the personal ability to reduce risk of death or injury". It is not clear therefore whether a worker who chooses a riskier occupation or industry has a higher risk preference or is more skilled at avoiding injury or both. Thus Shogren and Stamland (2002) argue that VSL estimates will be biased upwards as the highest wage differential among workers is divided by the average risk across the population. Thus, as Kniesner *et al*. (2005) point out, the expected direction of any bias is reversed depending on whether it is general or safety related productivity that is the focus of attention.[10] Although valid for nonfatal risk, for reasons previously discussed, the nature of pollution exposure means that unobservable safety related productivity is less of a pervasive argument as all workers in an industry are likely to experience similar pollution exposure levels regardless of *skill*.[11]

2.2 The Importance of Controlling for Inter-Industry Wage Differentials

There remains a further obstacle to the estimation of an industry level pollution-wage premia and that is the acknowledged existence of inter-industry wage differentials. Hence, we must take care to distinguish industry wage premia that are a result of pollution and premia that may exist for other reasons. Failing to control for other

[10] Kneisner *et al.* (2005) show that, ignoring measurement errors, omitting heterogeneity leads to an overestimate of VSL by a factor of four whereas it is underestimated by a factor of three if measurement errors are ignored and heterogeneity is included. Their final VSL estimates from a first difference analysis were below the median of the existing literature at between $5.3m and $6.7m in 2005 prices.

[11] There are numerous other concerns with the use of VSL estimates from labour market studies to evaluate environmental programs. First, the majority of labour market studies involve the use of fatality statistics while pollution-related deaths are likely to be the result of cumulative risks with potentially long latency periods. Second, the concept of risk in the standard labour market study is related to routine exposure to a given risk rather than involuntary exposure to pollution. Third, the effects of pollution might differ across different groups of people, those that are most at risk from exposure to pollution are likely to be the very young and old and those with a predisposition to chronic respiratory or cardiovascular conditions (for air pollution).

sources of industry wage premia would therefore bias the results. Broadly speaking, blue-collar workers in mining; construction; manufacturing; and transportation receive relatively high wages while those in wholesale; retail; finance; and services, receive lower wages (Leigh 1993). This general pattern of wage disparity is consistent across industry category definitions, time and countries. Dickens and Katz (1987) and Kruger and Summers (1987) find the structure of inter-industry wage differentials to be remarkably stable over time and also robust to the choice of model and data.

One criticism of much of the early work on compensating wage differentials is the argument that partial correlations between fatal injury rates and wages are due to coincidental patterns of wages and death rates across broad divisions. For example, mining and transportation have other characteristics that may lead to higher wages such as long hours and shift work. To illustrate this point, Leigh (1995a) found positive and significant coefficients on risk in his study using the 1982 Panel Study of Income Dynamics (PSID) and both the Bureau of Labor Statistics (BLS) and the National Institute for Occupational Safety and Health (NIOSH) measures of fatal risk (supporting the results of the previous literature). However, when broad industry dummies were introduced to account for inter-industry wage differentials neither risk variables were significant.[12]

The inter-industry wage literature has provided many explanations for the persistence of pay differentials. Brown and Medoff (1989) for example demonstrate that, *ceterius paribus*, larger employers pay higher wages although interestingly hazardous working conditions do not affect wages (Kruse 1992 and Brown and Medoff 1989). Other explanations for inter-industry wage differentials include compensating for the likelihood of sectoral unemployment (Murphy and Topel 1987), regional unemployment (Blanchard and Oswald 1994), union power or segmented markets (Dickens and Katz 1987) or industry shocks that persist over many years due to labour immobility or a larger proportion of experienced or tenured workers in particular

[12] When Dorman and Hagstrom (1998) used alternative measures of risk and included industry level variables they recorded dramatically different measures of wage compensation. Their strongest finding was actually that non-union members received negative compensation. That is to say, that they work in relatively high-risk jobs for low wages. Dillingham (1985) found that using a full set of occupation and industry dummies reduced both the size and significance or his risk coefficients. Occupation dummies reduced the risk coefficient by 50% while industry dummies cut them by more than 75%.

industries (Helwege 1992). Union density has also been investigated as a determinant of inter-industry pay differentials and numerous studies argue that highly unionised industries have a greater opportunity to influence wage decisions (and working conditions).[13] See Ashley and Jones (1996) and Currie and McConnell (1992) for examples of studies that include similar industry level variables to determine inter-industry wage differentials.

Within the inter-industry wage differential literature there is still considerable debate about the extent to which unobserved individual heterogeneity is responsible for inter-industry wage differentials (see e.g. Blackburn and Neumark 1992 and Gibbons and Katz 1995). Hence, individual level characteristics are often included to control for individual heterogeneity. The individual controls are generally the same as those used in the VSL literature.[14]

2.3 The Link Between Pollution and Health

The final piece of the jigsaw is the link between pollution and health. When we consider the health implications of pollution, the effects of ozone and Particulate Matter (PM10) are those most usually studied because it is these substances that most frequently exceed air quality guidelines. The health risks due to air pollution (specifically ozone and PM10) are quantified by estimating the relationship between the incidence of adverse health effects and air quality. A number of quantitative estimates of exposure-response relations of known health effects from various cities have been pooled together (meta-analysis).[15]

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[13] See Fenn and Ashby (2004) for a discussion and Viscusi and Aldy (2003) for a review of the studies analysing trade union effects. There is an argument that union density is endogenous in that union density may influence risk but also that it may be simultaneously determined by workplace risk although such an analysis is beyond the scope of this paper.

[14] Dickens and Katz (1987) find that roughly a quarter of individual level wage variation is explained by industry level wage premia and cast doubt on the ability of unmeasured worker heterogeneity to account for industry wage differentials.

[15] Ozone pollution stems mainly from emissions of Nox and VOC's with concentration levels depending on the amount and location of emitted pollutants, geographical characteristics, meterorological conditions, and atmospheric chemistry and transport. Ozone formation is complicated and non-linear, for example, under certain conditions an increase in Nox can reduce ozone concentrations. PM10 pollution stems mainly from direct emissions of particles, and from reactions of NOX and SO2 with other substances in the atmosphere. Potential emission sources are building and construction, diesel trucks and buses, forest fires, refuse burning and some manufacturing industries. See Cesar *et al*. (2001) for details.

Air pollutants can affect health in a number of ways, including eye irritations, respiratory diseases, cardiovascular effects and premature death. The adverse effects of air pollution are related to the rate at which lung tissue ages and can contribute to chronic lung and cardiovascular disease. Short-term peaks in air pollution (and hence acute exposure) can affect people in weakened states (such as those with pneumonia or asthma) and can lead to premature death. Dockery *et al*. (1993) and Pope *et al*. (1995) are two studies that follow a cross section of individuals across time and measure both the exposure to air pollution and other factors that may lead to premature death. These studies calculate survival functions (the probability that a person survives to each age in a given community) and find that pollution results in the loss of a significant number of life-years.

3. Methodology and Data

In any econometric investigation into compensating wage differentials it is important to be aware that the raw data tends to show a raw correlation between risk (however measured) and lower wages (Robinson 1991). Evidence of wage compensation is, therefore, dependent on the econometric specification.

In this paper we have gone to considerable lengths to ensure that we identify the relationship between risk (pollution intensity and nonfatal workplace injuries) and wages employing the most reliable and complete data available and as defensible a specification as possible. Hence, we use economic theory and previous empirical studies wherever possible to justify our choice of explanatory variables.

Assume individual i has a choice of jobs from a range of different possibilities and that each job offers different probabilities of job related ill health either through nonfatal injury or the existence of numerous pollutants known to be detrimental to health. Let r_{it} and p_{jt} represent the probability of non-fatal and pollution related risk for a particular job respectively. In order to examine the impact of pollution exposure and nonfatal risk on wage rates we estimate a standard semi-log wage equation (1):

$$\ln w_{it} = \beta_0 + \beta_1 p_{jt} + \beta_2 r_{jt} + \beta' X + \varepsilon_{it} \quad (1)$$

where w_{it} denotes the wage of individual i in year t, p_{jt} represents pollution exposure (defined below) in industry j, r_{jt} represents nonfatal risk in industry j and X is a vector of other determinants of wages that includes industry and individual level characteristics. ε_{it} is the error term.

3.1 Data

Our dependent variable is the log of wages and is measured as an individual's weekly wage. Estimates employing hourly wages gave broadly similar results.[16]

Pollution exposure p is trying to capture the degree of pollution exposure that an individual is subjected to in the workplace. Ideally, individual level or plant level measures of exposure would be employed but unfortunately neither were available. Instead, we utilise the industry level emissions of 21 different pollutants which we weight according to toxicity and aggregate into four broad groups. Throughout this paper we employ industry definitions used by the UK Environmental Accounts (EA). The EA categorisation is based on the Standard Industrial Classification 1992 (SIC92). Our 81 industries provide coverage for all sectors of the economy. In all we have six primary industries, 39 secondary and 33 service industries. See Appendix 1 for a list of industries included in our sample. We believe this provides a comprehensive cross section of the UK economy.[17]

In order to weight by toxicity we use the Threshold Limit Values (TLVs) reported in the American Conference of Governmental Industrial Hygienists (ACGIH) publication '2004 Threshold Limit Values for Chemical Substances and Physical Agents'. As Brooks and Sethi (1997) clarify, a TLV is the maximum airborne concentration of a substance to which a worker may be repeatedly exposed for an

[16] The difference between weekly pay and hourly pay is that the former includes usual hours of paid overtime.
[17] The UK Environmental Accounts (EA) use a combination of 2, 3 and 4-digit SIC codes. See http://www.statistics.gov.uk/.

eight-hour workday and 40 hour working week without suffering adverse health effects. Of our 21 pollutants, CO_2 has the highest TLV at 9,000 mg/m^3 while arsenic has the lowest TLV at 0.01 mg/m^3. Having weighted each pollutant by its TLV we then aggregate the 21 weighted pollutants into four groups, namely: (i) all 21 pollutants; (ii) heavy metals; (iii) traditional local air pollutants; and (iv) other pollutants (all non-heavy metals). See appendix 2 for a list of the pollutants included in each of our four groups.

Our aim is to proxy the pollution an individual is exposed to working in firm f in industry j. We denote this exposure EXP_{fj}. Since our four pollution groupings are measured at the industry level, we provide three alternative proxies of EXP_{fj}. Taking heavy metals for illustrative purposes, our three alternative measures are defined below;

Measure 1, which we call '*Polln*', is simply defined as total heavy metal emissions in industry j.

$$EXP_{fj} = HEAVYMETALS_j = Polln$$

Polln would be an appropriate measure of the heavy metal exposure from working in firm f if all industries have the same number of firms.

Measure 2, which we call '*PollnVA*' is defined as total heavy metal emissions in industry j divided by gross value added (GVA) in industry j.

$$EXP_{fj} = \frac{HEAVYMETALS_j}{GVA_j} = PollnVA$$

PollnVA would be an accurate measure of the heavy metal exposure from working in firm f if all firms in industry j produce the same GVA.

Measure 3, which we call '*PollnFIRM*' is defined as total heavy metal emissions in industry j divided by the number of firms in industry j.

$$EXP_{fj} = \frac{HEAVYMETALS_j}{No.FIRMS_j} = PollnFIRM$$

PollnFIRM would be an accurate measure of the heavy metal exposure from working in firm *f* if all industries had the same number of firms.

As stated, each measure only provides an accurate measure of EXP_{jf} if certain assumptions hold. Unfortunately, data limitations prevent us from ascertaining which of the three measures is the most or least likely to be the best proxy. For that reason and as a means of sensitivity analysis all three measures are tested for each of our four pollution groupings.[18]

Our individual level characteristics and nonfatal risk variable are obtained from the Quarterly Labour Force Survey (QLFS). We use micro data for males and females taken from all quarters of the QLFS for 1995-2003.[19] The main advantage of the *QLFS* is that it contains a wealth of information on the employment and socio-economic characteristics of individuals. Included are questions on economic activity such as employment status, industry of employment, size of industry and occupational status. More importantly, the QLFS includes four questions on workplace injuries on the winter quarters of the LFS from 1993/94 onwards. The questions ask respondents if they have suffered an accident that resulted in injury at work or in the course of work in the 12 months before the LFS interview. Injury rates are derived as the ratio of the estimated number of employed people who have suffered a workplace injury in the 12 months prior to the interview in a given industry, to the estimated number of

[18] It is easy to think of reasons why industry level emissions, however measured, are not accurate measures of exposure. For example, if pollution is emitted from a high chimney it is possible that local residents would suffer more from the fallout that those employed in the factory. Likewise, plant location or industrial clustering may have a significant affect on exposure levels not captured by our variables.

[19] The *QLFS* is a pseudo panel that follows the same individuals for five consecutive quarters. It currently includes a representative sample of approximately 60,000 households that is made up of five "waves", each of approximately 12,000 private households. A systematic random sample design is used for the survey and it is therefore representative of the whole of Great Britain. All estimates based on the LFS are subject to sampling error. Our sample is restricted to employees and excludes the self-employed.

people employed in a given industry at the time of the interview.[20] Our sample size is approximately 160,000.

A final issue is the possibility of selection bias as a result of assigning average industry (or occupation) risk to individual workers (Lipsey 1976). Note that a statistically significant positive coefficient on our pollution measures represents a wage premium captured by the employee for working in a dirty or dangerous industry. It is therefore an industry wage premium that is shared by all workers in that industry whatever their (unobservable) level of individual risk. For example, shop floor workers in a chemical plant are assumed to have the same risk premium as the secretaries working in the offices possibly away from the source of the pollution or injury risk. Nearly all the previous work in this area, with the exception of Duncan and Holmlund (1983), merge industry or occupation level fatal and non-fatal injury risks to individual workers. The attribution of average measured risk to individuals may be inexact because categorical risk is likely be mis-measured and imperfectly correlated with individual risk.[21]

Returning to equation (1), alongside pollution exposure, vector *X* contains a large number of individual level and industry level explanatory variables. We therefore include a number of industry level variables motivated by the inter-industry wage differential literature. To account for the effect of industry and occupational dummies discussed by Dillingham (1985) and Leigh (1995a), we include, in addition to a set of industry level variables, a full set of industry dummies. This allows us to take account of the important inter-industry wage effect. We also include a set of 9 broad occupation dummies.[22]

We also include a large number of the variables used in Dickens and Katz (1987). We include firm size following Brown and Medoff (1989), unemployment rates by

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[20] This approach to deriving an incidence rate of injury is described in a special feature to the Employment Gazette.

[21] The majority of studies are US based and merge industry-average risk measures (BLS at 2 or 3-digit) or the NIOSH's National Traumatic Occupational Fatality project which reports fatalities by 1-digit industry. Seven of the eight studies summarised in Droman and Hagstrom (1998) use these data sets.

[22] Our occupation groups are Professional Occupations, Managers and Administrators, Associate Professional and Technical, Clerical and Secretarial, Craft and Related, Personal and Protective Service, Sales Occupations, Plant and Machine Operatives, Other Occupations.

sector (Murphy and Topel 1987) and by region (Blanchard and Oswald 1994), union power or segmented markets (Dickens and Katz 1987) or industry growth and industry size (Helwege 1992). We also include union density, general health and job tensure.[23]

As applying industry-averaged data to individuals reduces the number of truly independent variables we cluster our standard errors by our industry classification because we are adjusting the standard errors for unobserved industry attributes (Moulton 1990).

To account for as much unobserved individual heterogeneity as possible we include a range of individual level characteristics to control for individual heterogeneity. For example, following Leeth and Ruser (2003) we include sex and ethnic dummies as well as the standard human capital controls for an individual level wage equation such as region of residence, qualifications, age, tenure, a measure of general health and occupation.[24] We split ethnicity into 9 groups, White, Black Caribbean, Black African, Black Other, Indian, Pakistani, Bangladeshi, Chinese and Other ethnic and include 11 UK regions, North, Yorkshire, North West, East Midlands, West Midlands, East Anglia, South East, South West, Wales, Scotland, Northern Island.

To address the productivity issues of Hwang *et al*. (1992) and Shogren and Stamland (2002) include five different levels of qualifications to proxy unobservable productivity or skills namely: A degree; A levels; O levels; other qualifications; and no qualifications.

The main results are derived from a full sample of both, males and females, manual and non-manual workers. With respect to the latter, there is some debate on whether we should be using data for production workers only (Costa and Kahn 2004). We believe, however, that if possible it is important to use of full sample of

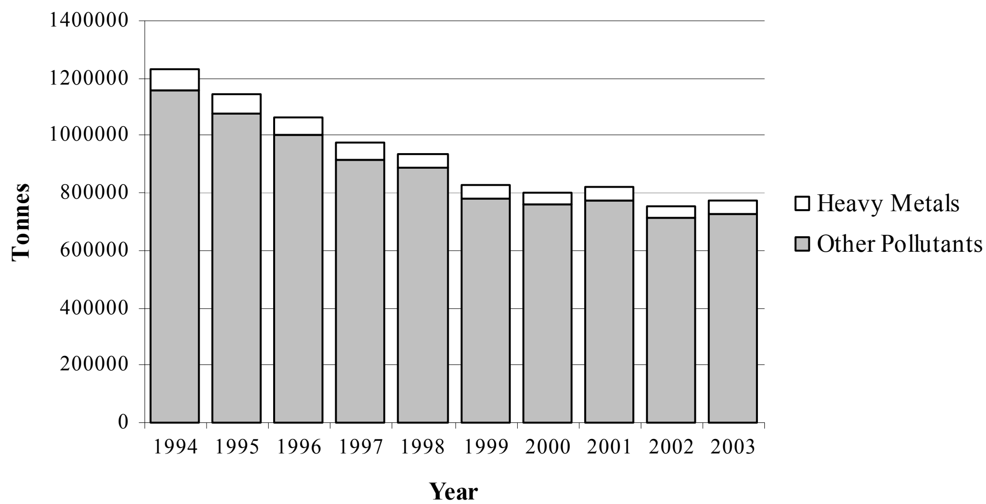
[23] We do not include import and export variables as our sample includes both tradable and non-tradable sectors. In addition we include workers in the transport industry although we acknowledge that this industry exhibits above average risk. However, this type of risk is likely to be weighted towards motor vehicle accidents that an individual is likely to believe are a result of their own behaviour and not that of their employers

[24] Whether an individual is a homeowner was initially included but dropped due to the standard endogenity concerns. The positive sign and significance was as expected.

manufacturing sectors and non-manufacturing sectors, blue-collar workers and white-collar workers. We interact our pollution variable with a manual worker dummy to account for the possibility that pollution affects manual and non-manual workers differently. Further debate about our exact specification is included in section 5.[25]

4.1 Descriptives

Table 1 presents the average pollution intensities for *Heavy Metals* and *Other Pollutants* (the sum of which is equal *Total Pollution*) between 1994 and 2003.



Although we do not observe the steep decline in emissions that occurred during the late 1980's and 1990's Figure 1 does reveal a general downward trend with a levelling off in recent years. Although not presented for reasons of space, the emissions intensity of the UK manufacturing sector as a whole has fallen over the period 1990-2000. However, whilst SO_2 and pm10 have fallen rapidly, CO_2 intensity has fallen very slightly, reflecting the absence of any notable decrease in total energy intensity.

[25] Data ability has limited the samples of numerous studies. For example, Bellman (1994) using occupational risk variables for blue-collar workers for Germany and finds a significant positive effect for non-fatal occupational illness of male employees, controlling for schooling, experience and change of industry. However, for nonfatal injuries at work the coefficient was significant and negative and concluded that for Germany there was no explicit evidence for the existence of compensating wage differentials, especially for non-fatal risks. Grund (2000) does, however, find evidence of compensating wage differentials for increased accidents for blue-collar workers in West Germany. A further justification for our manual and non-manual interaction term is that, for even the highest paid blue-collar workers, it is hard to entirely avoid risk in their job. Likewise, following Costa and Kahn (2004) there may be an argument for looking at male production workers between the age of 18 to 45 (or prime aged males) who are those individuals that are likely to be the most sensitive to risk (Viscusi and Aldy 2003).

Such aggregated data however, mask different trends at the individual industry level. Whilst emissions intensities are falling for some industries and some pollutants, for others we observe notable increases.

Results

In this section we estimate the determinants of wages as a function of pollution exposure and other individual and industry level characteristics. In Table 1 we provide the coefficients on our pollution and nonfatal risk variables.

The coefficient on pollution for manual and non-manual workers are presented separately following the argument that pollution will affect these workers differently due to the possibility of a variance in exposure levels even within the same industry depending on whether the job is manual or non-manual. The default individual in our regressions is a native born; white; male; has no qualifications; lives in the South West; works in the agricultural industry and is classified as having an "other occupation".

Table 1. The impact of pollution on (log) wages (estimated coefficients).

		Polln	PollnVA	PollnFirm
All Pollutants	Manual	0.27***	1.39**	44.31***
		(0.093)	(0.65)	(7.43)
	Non-manual	-0.13	-1.00	-12.26
		(0.15)	(1.07)	(9.47)
	Risk	-0.050	-0.049	-0.049
		(0.088)	(0.089)	(0.088)
Heavy Metals	Manual	8.16**	16.46**	2658.76***
		(4.04)	(7.57)	(610.18)
	Non-manual	0.23	-5.70	-1062.52**
		(4.03)	(8.12)	(513.71)
	Risk	-0.052	-0.047	-0.050
		(0.087)	(0.089)	(0.088)
Local Air	Manual	0.29***	1.57***	46.53***
		(0.091)	(0.72)	(7.15)
	Non-manual	-0.14	-1.06	-12.68
		(0.15)	(1.16)	(9.80)
	Risk	-0.050	-0.049	-0.048
		(0.088)	(0.089)	(0.088)
Other Pollution	Manual	0.27***	1.47***	44.64***
		(0.095)	(0.69)	(7.07)
	Non-manual	-0.14	-1.12	-12.06
		(0.16)	(1.16)	(9.53)
	Risk	-0.050	-0.050	-0.048
		(0.088)	(0.089)	(0.088)
	R^2 (all models)	0.53	0.53	0.53
	n (all models)	160,150	160,150	160,150

Standard errors in parentheses, ***, ** and * denote significance at 99%, 95% and 90%, respectively. The R^2 was approximately 0.53 for each alternative specification but does not refer to an individual regression, likewise for *n*.

The coefficients on *manual* are positive and significant across all twelve different combinations of pollution type and measure of exposure. The other results are similarly consistent. *Non-manual* is broadly negative and insignificant with the exception of Heavy Metals for *pollnfirm* with a significant negative coefficient.

Our nonfatal *risk* variable is also insignificant and negative and is largely as expected given the inclusion of detailed industry and occupation dummies.[26]

Care must be taken with the interpretation of the coefficients in Table 1. For example, a coefficient of 0.27 for all pollutants for manual workers means that a one unit increase in *Polln* leads to a 27% increase in the log of wages. Although, by similar reasoning, Table 1 shows that a one-unit increase in Heavy Metals per firm leads to a 265,800% increase in the log of wages, it must be recognised that a one-unit increase in Heavy Metals per firm is likely to be highly toxic and highly unlikely.[27]

Turning to the other explanatory variables (not reported) the results are broadly as expected. A full specification for Total Pollution and Heavy Metals for *Polln* can be found in appendix 3.

As determinants of wages the following are broadly negative and significant: regional unemployment; female; age squared and health. Physical capital intensity (PCI) and growth in gross value added (GVA) are generally negative and insignificant. Broadly positive and significant determinants of wages are: union density; GVA; the size of the firm; sectoral unemployment; individual age; qualifications; whether foreign born; and whether married. Whether working in the manufacturing sector is positive but insignificant. These results are all as expected expect perhaps the sectoral unemployment rate.

Table 2 presents the elasticities for our pollution variables for each specification.

[26] Results not including industry and occupation dummies are available from the authors upon request.
[27] Strictly speaking a coefficient of 0.27 means that a 1 unit increase in the explanatory variable will increase wages by exp(0.27)-1)*100 = 31%.

Table 2. The impact of pollution on wages (estimated elasticities).

		Polln	PollnVA	PollnFirm
All Pollutants	Manual	0.0012	0.00075	0.00021
	Non-manual	-0.00064	-0.00058	-0.00010
Heavy metals	Manual	0.000075	-0.00024	-0.00024
	Non-manual	0.0022	0.00063	0.00037
Local Air	Manual	-0.00059	-0.00052	-0.000096
	Non-manual	0.0011	0.00072	0.00019
Other Pollution	Manual	0.0011	0.00073	0.00020
	Non-manual	-0.00063	-0.00060	-0.000098

Standard errors in parentheses, ***, ** and * denote significance at 99%, 95% and 90%, respectively.

If we consider as an example, Heavy Metals and manual workers measuring pollution as *PollnFirm*, it reveals that a 1% increase in Heavy Metal pollution per firm raises wages by 0.00037%. Similarly, a 1% increase in All Pollutants for manual workers and total pollution leads to a 0.0012% increase in wages.

The values in Table 2 are reassuringly small. Given the industry specific nature of the many pollutants, it would be surprising if, across all manufacturing, primary and service sectors, that pollution had a large effect on wages. Our next step, therefore, is to include interaction terms for some of the dirtiest sectors to see which sectors generate the largest positive wage premia. Industries were therefore ranked across all four groups of pollutants and then ranked again to get an overall approximation of the ten dirtiest industries from our sample of 81.

Table 3 and Table 4 present the estimated coefficients and elasticities respectively. The interpretation of the *manual* coefficients by industry is the effect of pollution on wages for a manual worker in that industry over and above the effect of pollution on wages for manual workers overall.

Table 3. The impact of pollution on wages in dirty industries (all pollutants only, estimated coefficients)

	Polln	PollnVA	PollnFirm
Manual (Excluding the dirtiest ten)	0.15	-0.25	1402.61**
	(0.48)	(0.90)	(641.01)
Electricity Production (SIC401)	0.087	1.89***	-1361.56**
	(0.48)	(0.51)	(641.03)
Coke ovens, refined petrol & nuclear	3.08***	6.65***	-442.27
(SIC23)	(0.61)	(0.84)	(606.01)
Iron and Steel (SIC271-273)	3.19***	3.83***	1821.13***
	(0.56)	(0.64)	(604.81)
Other Organic Basic Chemicals	15.50***	20.73***	1160.71**
(SIC2414)	(2.01)	(2.47)	(599.79)
Non-Ferrous Metals (SIC274)	7.54***	6.66***	4631.00***
	(1.49)	(1.53)	(1135.44)
Extraction of Petrol & Gas (SIC11 +12)	9.50***	130.12***	11100.49***
	(0.96)	(11.86)	(1012.56)
Other Inorganic Chemicals (SIC2413)	12.14***	4.65**	2306.95**
	(4.10)	(1.66)	(1106.94)
Sewage and Waste (SIC90)	3.25**	11.49**	3432.58*
	(1.65)	(5.48)	(2003.91)
Structural Clay Products (SIC264)	15.29***	3.40**	2088.77**
	(4.21)	(1.37)	(994.20)
Industrial Gases, Dyes & Pigments	45.84***	32.66***	44.38
(SIC2411 + 2412)	(6.64)	(4.73)	(591.37)
R^2	0.53	0.53	0.53
n	160,150	160,150	160,150

Standard errors in parentheses, ***, ** and * denote significance at 99%, 95% and 90%, respectively. Comparable results for heavy metals, local air pollution and other pollution are available from the authors upon request. Note that since coefficients estimated for non-manual workers in this table and in Table 1 are not statistically significant, industry specific coefficients are presented for manual workers only.

For *Polln* and *PollnVA* each industry records an additional positive effect. Two industries (SIC401 and SIC23) record negative values for *PollnFirm* although these are still below the overall *manual* value. Again, it is useful to look at the estimated elasticities to get an impression of the impact of pollution across individual industries. These are presented in Table 4.

Table 4. The impact of pollution on wages in dirty industries (all pollutants only, estimated elasticities).

	Polln	*PollnVA*	*PollnFirm*
Manual	0.00067	-0.00014	0.0065
Electricity Production (SIC401)	0.00072	2.7E-06	0.0013
Coke ovens, refined petrol & nuclear (SIC23)	0.00085	0.000032	0.0064
Iron and Steel (SIC271-273)	0.0011	0.00014	0.0068
Other Organic Basic Chemicals (SIC2414)	0.00068	-0.00012	0.0065
Non-Ferrous Metals (SIC274)	0.00077	-6.26E-05	0.0066
Extraction of Petrol & Gas (SIC11 + 12)	0.00087	0.000058	0.0067
Other Inorganic Chemicals (SIC2413)	0.00069	-0.00012	0.0065
Sewage and Waste (SIC90)	0.00082	-8.4E-06	0.0066
Structural Clay Products (SIC264)	0.00071	-0.00011	0.0065
Industrial Gases, Dyes & Pigments (SIC2411 + 2412)	0.00071	-9.83E-05	0.0065

Note that the overall elasticity is the addition of the manual coefficient and the industry elasticity. SIC401 for example would be 0.00067+0.00072.

Note that the industry coefficients are over and above the *manual* elasticity value of 0.00067. The true industry elasticity is therefore the addition of 0.00067 and the industry specific coefficient. If we assume a linear relationship between pollution and wages we might expect the elasticities to be the same across all industries. That is to say, the wage premium demanded by workers for working in a pollution-intensive industry should be equal for a given level of pollution. Indeed, for *PollnFirm* the firm specific elasticities are almost identical at around 0.0065. There are significant differences for *Polln* and *PollnVA* however. One interpretation is that these differences are picking up a degree of over or under compensation that may in turn be related to so-called “threshold” effects. Hence, an industry with an already high level of pollution will have a more than proportionate increase in wages as a result of a 1% increase in pollution. Likewise, a relatively clean industry can increase pollution considerably before workers begin to demand any degree of wage compensation.

In Table 5 we present the actual industry level wage premiums for our ten dirtiest industries. We present the actual weekly wage premium is pounds sterling and the percentage of the weekly wage that this constitutes.

Table 5. Wage premiums in dirty industries (Pounds £ per week and as a percentage of the average weekly wage in each industry)

	Polln	%	PollnVA	%	PollnFirm	%
SIC401	21.50	6.7	17.20	5.4	21.70	6.8
SIC23	47.70	13.4	42.10	11.8	51.20	14.4
SIC271-273	36.50	13.2	20.50	7.4	37.20	13.4
SIC2414	45.70	13.5	45.00	13.3	38.90	11.5
SIC274	18.80	7.4	13.70	5.4	17.80	7.0
SIC11+12	77.30	18.4	72.40	17.3	74.40	17.7
SIC2413	17.00	5.7	13.80	4.6	16.10	5.4
SIC90	8.50	3.8	7.00	3.1	7.30	3.3
SIC264	14.40	5.5	8.20	3.1	13.70	5.2
SIC2411 +2412	37.60	13.7	34.10	12.4	12.20	4.5
Ave. for all 81 industries	0.80	0.3	1.60	0.7	0.40	0.2

Note: This table identifies how much lower manual wages would be in these industries if pollution were equal to zero. Wage premiums based upon the level of wages if pollution were equal to the median level of pollution across all industries are very similar to these, reflecting the fact that the median level of pollution is very low and hence close to zero. Wage premiums calculated using the mean level of pollution across industries are, inevitably, smaller and are available upon request but, averaged across the dirtiest industries are equal to £28.80, £13.80 and £20.60 for our three measures of polln, pollnVA and pollnFirm, respectively.

For *Polln*, if we exclude the Extraction of Oil and Gas (SIC11+12), that may have a large premium for reasons not controlled for in this paper such as shift work and unsociable working conditions, the largest wage premiums in percentage terms are around 13% for Coke ovens, refined petrol and nuclear (SIC23), Iron and Steel (SIC271-273), Other Organic Basic Chemicals (SIC2414) and Industrial Gases, Dyes and Pigments (SIC2411+2412). In absolute terms this translates into an increase in the weekly wage of between £36 and £50.

There is remarkably little difference across our measures of pollution exposure in terms of magnitude or ranking of industries that gives us some confidence that are three alternative measures are indirectly capturing an individuals pollution exposure.

In addition to the results presented above we undertook a large array of sensitivity and robustness checks. First, we attempted to implement the Garen (1988) procedure to account for the endogeneity concerns about self selection and unobserved productivity raised by Shorgen and Stamland (2002). Our estimation strategy was to instrument for nonfatal risk and pollution risk and also to estimate 3SLS. Whilst we were able to find suitable instruments for nonfatal risk such as partner's wage and number of children we could find no instruments to adequately capture pollution risk. Estimations instrumenting for nonfatal risk has little effect on the coefficients on either nonfatal risk or pollution. Results are available upon request. In common with the majority of the wage-premium literature, we are therefore unable to fully control for endogeneity and hence our results should best be interpreted as conservative estimates. Secondly, we re-estimated our results using different combinations of industry and occupation dummies. As expected, the exclusion of these dummies improved our coefficients on both pollution and risk. These results are excluded for reasons of space.

Conclusions

The compensating wage literature is well established and numerous papers investigate both the causes in inter-industry wage differentials and how these differentials, applied to fatal and nonfatal risk, can be used to estimate the VSL. In this paper we investigate, for the first time, whether an industry's level of pollution emissions weighted by toxicity is sufficient to generate a wage premium for working in a dirty industry. Although theoretically and intuitively plausible, we discuss numerous empirical and theoretical arguments as to why exposure to pollution may not be translated into greater wage demands and hence a wage premium. However, after taking care to fully specify our econometric model in light of these arguments our results suggest wage premia estimates of one half of one percent were observed across all sectors of the economy although this rose to approximately 10% for workers in the dirtiest industries. Our results are also robust to numerous endogeneity concerns.

Finally, it would be interesting to extend the analysis in this paper to investigate the relationship between industry emissions and the incidence of ill-health or sickness absence. Our work could also be extended by the use of industry level fatality statistics to provide some of the first VSL estimates for the UK and to compare these estimates with those of the US.

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Appendix 1

EA Industry Classification and SIC92 concordance

SIC92	Description	SIC92	Description
1	Agriculture	32	Radio, television and comms.
2	Forestry	33	Medical, precision, optical inst.
5	Fishing	34	Motor vehicles and trailers
10	Mining of coal	35	Other transport equipment
11+12	Extraction of petrol and gas	36+37	Manufacture of other products
13	Mining of metal ores	40.1	Electricity production
14	Other mining	40.2+40.3	Gas distribution
15	Food and beverages	41	Water supply
16	Tobacco products	45	Construction
17	Textiles	50	Garages, car showrooms
18	Clothing manufacture	51	Wholesale trade not motor vehicles
19	Leather, luggage & footwear	52	Retail & repair except motor
20	Timber	55	Hotels and restaurants
21	Pulp and paper	60.1	Railways
22	Publishing and printing	60.2+60.3	Buses and coaches
23	Coke oven, refined petrol & nuclear	60.2+60.3	Tubes and trams
24.11+24.12	Industrial gases, dyes, pigments	60.2+60.3	Taxis operation
24.13	Other inorganic chemicals	60.2+60.3	Freight transport by road
24.14	Other organic basic chemicals	60.2+60.3	Transport via pipeline
24.15	Fertilisers, nitrogen compounds	61	Water transport
24.16+24.17	Plastics and synthetic rubber	62	Air transport
24.2	Pesticides, agro-chemicals	63	Supporting transport activities
24.3	Paints, varnishes, ink etc	64.1+64.2	Post and telecommunications
24.4	Pharmaceuticals	65	Financial intermediation
24.5	Soap and detergents	66	Insurance and pensions
24.6	Chemical products n.e.s	67	Auxiliary finance activities
24.7	Man-made fibres	70.1+70.2+70.3	Real estate activities
25.1	Rubber products	71	Renting of machinery
25.2	Plastic products	72	Computer and related activities
26.1	Glass and glass products	73	Research and development
26.2+26.3	Ceramic goods	74	Other business activities
26.4	Structural clay products	75	public admininstration
26.5	Cement, lime and plaster	80	Education
26.6+26.7+26.8	Concrete, stone etc	85	Health and vet services, social work
27.1+27.2+27.3	Iron and steel	90	sewage and waste
27.4	Non-ferrous metals	91	Activities of membership orgs.
27.5	Casting of metals	92	Recreation and sporting activities
28	Fabricated metal products	93	Other service activities
29	Machinery & equipment	95	Private households
30	Office machinery, computers		
31	Electrical machinery & apparatus		

Appendix 2

Pollutants Groupings

All Pollutants	Heavy Metals	Local Air	Other Pollutants (all non-heavy metals)
Sulphur Dioxide		Sulphur Dioxide	Sulphur Dioxide
Nitrogen Oxides		Nitrogen Oxides	Nitrogen Oxides
Ammonia		Ammonia	Ammonia
Carbon Monoxide		Carbon Monoxide	Carbon Monoxide
Particulate Matter (pm10)		Particulate Matter (pm10)	Particulate Matter (pm10)
Non-methane Volatile Organic Compounds		Non-methane Volatile Organic Compounds	Non-methane Volatile Organic Compounds
Benzene			Benzene
Butadiene			Butadiene
Lead	Lead		e
Cadmium	Cadmium		
Arsenic	Arsenic		
Mercury	Mercury		
Copper	Copper		
Chromium	Chromium		
Nickel	Nickel		
Selenium	Selenium		
Vanadium	Vanadium		
Zinc	Zinc		
Carbon Dioxide			Carbon Dioxide
Methane			Methane
Nitrous Oxides			Nitrous Oxides