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

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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 a small wage premium of approximately one quarter of one percent associated with the risk of working in a dirty job. This premium rises to over fifteen percent for those individuals who work in one of the five dirtiest industries. We also find evidence of a fatal risk wage premium, providing estimates of the value of a statistical life of between £12 million and £19 million (2000 prices).

Keywords: Compensating Wage Differentials, Pollution, Value of Statistical Life.

JEL: J28, J31, Q52.

In recent years environmental concerns have crept up the political agenda. Alongside the recognition of how economic activity affects climate change there is also an increase in the awareness of how industrial emissions of a variety of pollutants can adversely affect the health of employees. Indeed, the recent Registration, Evaluation and Authorization of Chemicals law (REACH), one of the largest EU laws ever ratified, oversees the registration of around 30,000 chemicals and provides an EU body with the power to ban those chemicals that are deemed a health threat. According to Vineis and Simonato (1991), between 1 and 40% of lung cancers and 0 to 24% of bladder cancers are attributable to workplace exposure. Similarly, Landrigan (1992) estimates that in the US between 50,000 and 70,000 cancer deaths in 1990 were caused by work related toxic exposure together with 350,000 new cases of illness. Finally, the World Health Organization (WHO) estimate that 200,000 people die globally, each year, from cancer related to their workplace (WHO 2007).

Given these health concerns, in this paper we ask whether workers are compensated financially for working in a heavily polluting or dirty industry. We define ‘dirty’ as an industrial environment where an employee is potentially exposed to a high level of pollutants that may, in turn, have a detrimental effect on that individual’s health. If there is a 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. As such, workers in dirty industries should be fully compensated for the risks. An alternative way of thinking about this is that firms pollute the local environment and hence workers from the locality demand higher wages as compensation irrespective of work exposure levels. Thus it should be possible to calculate the wage premium associated with such employment by using a traditional hedonic wage methodology.

The theoretical case for efficient wage compensation rests on 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 labor markets are perfectly competitive. If any of these conditions fail to fully apply then the actual compensation may be less than utility offsetting or nonexistent. Conversely, compensation can be more than utility offsetting if workers overestimate the risk. 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. We use disaggregated industry-level pollution data and individual-level wages and characteristics. In addition we provide estimates of the value of statistical life (VSL) for the UK and the first estimates employing data from the UK Labour Force Survey (LFS). The main finding of our paper is the existence of a positive and significant wage premium attached to working in a dirty

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. Most value of statistical life (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. 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). Note that their estimates are considerably less than the Environmental Protection Agency (EPA) VSL value 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. See Viscusi (2007) for an overview of the regulation of health, safety and environmental risks

industry, across a range of pollution exposure measures. This finding is robust to a battery of sensitivity checks. The average weekly wage premium across all industries is found to be between £0.20 and £0.80 equivalent to between 0.1% and 0.4% of weekly wages. For the most pollution intensive industries the weekly wage premium is between £17.40 and £125.90, equivalent to between 6.5% and 30.0%. A secondary result is that we also find evidence of a weekly wage premium compensating for the risk of fatal accidents. Across all industries, this premium is between £1.30 and £1.50 per week, equivalent to between 0.54% and 0.63% of weekly wages. Finally, our fatal risk results provide estimates of the VSL of between £12m and £19m in 2000 prices, although we find no significant value of statistical injury.³

The remainder of this paper is organised as follows: Section 1 reviews the literature on the impact of pollution on health and also examines the wage-risk literature to identify the difficulties associated with estimating compensating wage differentials; Section 2 outlines our methodology and describes our data; Section 3 presents our results while Section 4 concludes.

1. Review of the Literature

Little has been written on the impact of industrial pollution on wages. In this section we discuss the relationship between wages, job risk and pollution. First, we briefly discuss how pollution can affect an individual's health and thus the riskiness of working in a given industry. Second, we consider the

³ UK estimates of VSL have often been notably different to those estimated for the US (see Viscusi and Aldy 2003).

factors that may hinder the estimation of pollution related wage-premia and conclude with a brief discussion of pollution risk within the context of the inter-industry wage differential literature.⁴

Our first consideration is the link between pollution and health. The effects of ozone and Particulate Matter (PM10) on health are those most commonly studied because it is these substances that most frequently exceed air quality guidelines (Cesar *et al.* 1999). 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). The findings are that air pollutants can affect health in a number of ways, including eye irritations, respiratory diseases, cardiovascular effects and premature death.⁵

⁴ There are a small 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. Cole and Elliott (2007) find a similar result for the UK. 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.

⁵ 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, meteorological 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.

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.

A final consideration is that although a significant amount of information is available on the effect on health of asbestos, vinyl chloride, 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. According to the WHO, the most common types of occupational cancers are lung cancer, mesothelioma and bladder cancer with every tenth lung cancer death being closely associated to risks in the workplace. In a recent WHO press release to mark World Day for Safety and Health at Work they write “Currently, most cancer deaths caused by occupational risk factors occur in the developed world. This is a result of the wide use of different carcinogenic substances such as blue asbestos, 2-naphthylamine and benzene 20-30 years ago”. 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).

In many cases, exposure to workplace pollutants would be obvious to the worker. Some chemicals have distinctive smells (e.g. sulfur) or would result in a loss of local visibility (e.g. particulate matter), while others would be evident because of their impact in causing eye irritation or tightness of breath. However, the presence of some pollutants would be less evident, particularly those that are odourless and cause only longer term health problems. There is only a small literature that discusses an individual's perceived pollution risk and hence the likelihood that an individual would demand a wage premium. There are several primary reasons why "dirty" wage premia may be difficult to identify empirically.

The first reason is a lack of knowledge by employers or employees, and the public, on the impact of pollution on health and disease (or a lack of awareness of the existence of pollution). This in turn may undermine the market's ability to generate compensating wage differentials. Shilling and Brackbill (1979) estimate that only about 5% of workers were fully informed of the job hazards of their occupations. In a related study, Brown (1987) interviewed workers in dangerous chemical plants and concluded that, although workers were fully aware of the risks that they faced, they employ a psychological defence mechanism of denial by refusing to believe that the probability of death or serious injury is high. This is less of a concern in this paper, as we do not use self-reported risk. However, in contrast, Viscusi and O'Connor (1984) find that US chemical workers *are* aware of the risks to which they are exposed and received compensating wage differentials comparable to those found for objective risk measures.

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. For

example, retirement, pensions, training, vacation pay etc. Lott and Manning (2000) and Wiggins and Ringleb (1992) examine this issue from a legal standpoint and show that allowing employees to sue their employer has resulted in firms reorganizing and divesting themselves of hazardous facilities in the hope of gaining protection from potential law suites.

Third, it can be argued that individuals' perceptions of risk are heterogeneous so, for example, ethnic minorities and those from lower socio-economic backgrounds may have different perceptions of risk or at least be less geographically 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. In a US study, Leeth and Ruser (2003) find 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.⁶ However, once the occupational

⁶ In a study for the US Viscusi (2003) reveals that blacks do face a higher fatality risk and nonfatal injury-risk but that the differences are not great. He also shows that black employees receive significant premia for nonfatal risks. 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 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 injury 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 premia were smaller than for white women.

distribution of workers is accounted for they find there is no premium for males but do find that men and women in blue-collar jobs earn a premium that does not exist for white-collar jobs.⁷

The existence of inter-industry wage differentials is a further obstacle to the estimation of an industry level pollution-wage premia. Failing to control for other sources of industry wage premia would 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 1995). The inter-industry wage literature has provided many explanations for the persistence of pay differentials. Brown and Medoff (1989) for example demonstrate that, *ceteris paribus*, larger employers will pay higher wages. Other explanations for inter-industry wage differentials include compensating for the likelihood of sectoral unemployment (Murphy and Topel 1987), regional unemployment (Blanchflower and Oswald 1994), union power or segmented markets (Dickens and Katz 1987) or industry shocks that persist over many years due to labor immobility or

⁷ A related issue is the controversy surrounding unobservable worker heterogeneity and VSL estimates. One recognised problem with all wage-risk studies is the issue of endogeneity, as raised by Garen (1988). 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). After attempting to control for endogeneity issues, Garen (1988) finds generally larger VSL estimates. 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 individuals' indifference curves are identical. The Garen technique therefore removes too much. Nevertheless, we utilise the Garen methodology to control for the possible endogeneity of our fatal, 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 are unable to instrument for possible endogeneity between wages and pollution intensity as no suitable instruments is available. Results when fatal and nonfatal risk are instrumented are available from the authors upon request.

a larger proportion of experienced or tenured workers in particular industries (Helwege 1992). Finally, numerous studies argue that highly unionised industries have a greater opportunity to influence wage decisions (and working conditions). See Duncan and Stafford (1980) and Viscusi and Aldy (2003) for a review of the trade union effect.

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 in the VSL literature.⁸

Wherever possible, we try to overcome the obstacles outlined above. To minimise the possibility of unobserved individual heterogeneity affecting wages we control for a wide range of individual characteristics when estimating wages, as discussed below. Similarly, the inclusion of industry-level dummies allows us to control for inter-industry wage differentials.

Whether or not workers are compensated ex post for the risks that they face and whether or not they are actually aware of these risks is an empirical question that further motivates our study. The fact that we find such premia to exist suggests that workers *are* at least partially aware of the risks that they are exposed to and, furthermore, they are not fully compensated for them ex post.

⁸ Dickens and Katz (1987) find that roughly a quarter of individual level wage variation is explained by industry level wage premia casting doubt on the ability of unmeasured worker heterogeneity to account for industry wage differentials.

2. Methodology and Data

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

In this paper we go to considerable lengths to ensure that we identify the relationship between risk (exposure to pollution and fatal and nonfatal injury) and wages. We use economic theory and previous empirical studies to justify our choice of explanatory variables.

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

$$\ln w_{it} = \beta_0 + \beta_1 p_{jt} + \beta_2 f_{jt} + \beta_3 r_{jt} + \beta' X + \varepsilon_{it} \quad (1)$$

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

Pollution exposure p is trying to capture the degree of pollution exposure that an individual is subjected to in the workplace. We utilise 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 Table 4 in the Appendix for a list of industries included in our sample. We believe this provides a comprehensive and representative cross-section of the UK economy. We acknowledge the existence of aggregation issues because of our industry level measures where the ideal measure of pollution exposure would be at the plant level but our choice is as disaggregated as possible given the data constraints.⁹

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 eight-hour workday and 40 hour working week without suffering adverse health effects. Of our 21 pollutants, CO₂ has the highest TLV at 9,000 mg/m³ while arsenic has the lowest TLV at 0.01 mg/m³. 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 Table 5 in the Appendix for details.

⁹ The UK Environmental Accounts (EA) use a combination of 2, 3 and 4-digit SIC codes. See <http://www.statistics.gov.uk/>.

We construct a proxy of individual exposure of working in firm f in industry j at time t denoted as EXP_{fjt} . We provide three alternative measures of EXP_{fjt} for each of our four pollutant groups where “emissions” are either total pollution, heavy metals, local pollutants or other pollutants. We describe each exposure measure and explain under which assumptions each proxy is an appropriate measure of exposure risk.

Measure 1, which we call ‘*Pollution*’, is simply defined as emissions in industry j .

$$EXPOSURE_{fjt} = EMISSIONS_{jt} = Pollution \quad (2)$$

Pollution would be a reasonable proxy of the pollution exposure from working in firm f at time t , if all industries have the same number of firms.

Measure 2, ‘*Pollution per unit of value added*’ is defined as total emissions in industry j scaled by gross value added (GVA) in industry j .

$$EXPOSURE_{fjt} = \frac{EMISSIONS_{jt}}{GVA_{jt}} = Pollution \text{ per unit of value added} \quad (3)$$

Pollution per unit of value added would be a reasonable proxy of the pollution exposure from working in firm f at time t , if all firms in industry j have the same level of GVA.

Measure 3, ‘*Pollution per firm*’ is defined as total emissions in industry j scaled by the number of firms in industry j .

$$EXPOSURE_{fjt} = \frac{EMISSIONS_{jt}}{No.FIRMS_{jt}} = Pollution\ per\ firm \quad (4)$$

Pollution per firm would be a reasonable proxy of the pollution exposure from working in firm f at time t if all industries have firms of the same size. We are unfortunately unable to ascertain which of our measures forms the most accurate measure of exposure. For that reason, and as part of our sensitivity analysis, all three measures are tested for each of our four pollution groupings. 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 than those employed in the factory. Likewise, plant location or industrial clustering may have a significant effect on exposure levels not captured by our variables. However, if pollution affects the local community wages may still reflect the demands of the local population who work in the polluting factory.¹⁰

Our individual-level characteristics are obtained from the Quarterly Labour Force Survey (QLFS). We use micro data for male and female manual workers taken from the QLFS for 1995-2003.¹¹ The main advantage of the *QLFS* is that it contains a wealth of information on the employment and

¹⁰ In unreported results we also use a fourth exposure measure, namely pollution per worker. Results were broadly similar to those for the other exposure measures but are omitted for reasons of space. They are available upon request.

¹¹ The *QLFS* is a rotating panel that follows the same individuals for five consecutive quarters. It currently includes a representative sample of approximately 60,000 households made up of five “waves”, each of approximately 12,000 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 excludes the self-employed. Care is taken to ensure that individuals are not replicated.

socio-economic characteristics of individuals. Our fatal and non-fatal data are from the Health and Safety Executive (HSE). This approach to deriving an incidence rate of injury is described in a special feature of the Employment Gazette (December 1992) by Stevens (1992). Our sample size is approximately 53,000 individuals. Our dependent variable is the log of wages and is measured as an individual's weekly wage. Estimates with hourly wages give broadly similar results.¹²

The main results in this paper are derived from a sample of male and female manual workers. Costa and Kahn (2004) consider only male production workers between the age of 18 to 45 (or prime aged males) who they argue are the individuals that are likely to be the most sensitive to risk (Viscusi and Aldy 2003). In our sensitivity analysis we therefore estimate our results for males only and for both production and non-production workers. Results are available upon request.¹³

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 any pollution variable represents a wage premium captured by the employee for working in a dirty 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 secretaries working in the offices

¹² The difference between weekly pay and hourly pay is that the former includes usual hours of paid overtime.

¹³ Bellman (1994) uses 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. He concluded that for Germany there was no explicit evidence for the existence of compensating wage differentials, especially for non-fatal risk. In contrast, Grund (2000) finds evidence of compensating wage differentials for increased accidents for blue-collar workers in West Germany.

possibly away from the source of the pollution or injury risk. Many previous studies in this area merge industry or occupation level fatal and non-fatal injury risks to individual workers (with some exceptions such as Duncan and Holmlund (1983) and Viscusi (2004)). The attribution of average measured risk to individuals may be inexact because categorical risk is likely to be mis-measured and imperfectly correlated with individual risk. We attempt to minimise this potential problem by concentrating on manual workers.¹⁴

Returning to equation (1), alongside pollution exposure, vector X contains a large number of individual-level and industry-level explanatory 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 (1995), we include a broad occupation dummy and sector dummies. This allows us to take account of the important inter-industry wage effect. We also include firm size following Brown and Medoff (1989), unemployment rates by region (Blanchflower and Oswald 1994), union power or segmented markets (Dickens and Katz 1987), industry growth and industry size (Helwege 1992) and the capital intensity of an industry.¹⁵ Because applying industry-averaged data to individuals reduces the number of truly independent variables we cluster our standard errors by our industry classification to adjust the standard errors for unobserved industry attributes (Moulton 1990).

¹⁴ 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.

¹⁵ Import and export variables are not included as our sample has both tradable and non-tradable sectors.

To account for as much unobserved individual heterogeneity as possible we include a range of individual level characteristics. For example, following Leeth and Ruser (2003) we include sex, a foreign born dummy and ethnic dummies as well as the standard human capital controls for an individual level wage equation such as region of residence, qualifications, age, marital status, tenure, and a measure of general health. Whether or not an individual is a homeowner was initially included but dropped due to the standard endogeneity concerns. The positive sign and significance was as expected and the results for other variables do not change. We also 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; and Northern-Ireland. To address the productivity issues of Hwang *et al.* (1992) and Shogren and Stamland (2002) we include five different levels of qualifications to proxy unobservable productivity or skills namely: a degree; A-levels; O-levels; other qualifications; and no qualifications. Finally to control for other potentially undesirable job attributes we include a dummies for shift-working, evening work and night work.

3. Results

Our results stems from estimates of equation (1) for our three alternative exposure measures and four different pollutant groups. In Table 1 we report the OLS coefficients on our pollution, fatal and nonfatal risk variables for each of the twelve individual specifications. Table 1 also reports the

coefficients on pollution from a base specification where fatal and nonfatal risk are omitted, again for the twelve different specifications.¹⁶

[Table 1 about here]

In line with the previous VSL literature we find a significant and positive coefficient on fatal risk that is fairly constant across pollutants and pollution risk variables. When we calculate the VSL based on an average wage of £11,460 and 2000 prices the estimates range between £12 million and £19 million (US\$17.8 and US\$28.1 at an average year 2000 exchange rate of 1.48). This range is considerably higher than US estimates but is more consistent with previous UK studies. For example, again using 2000 prices, Arabsheibani and Marin (2000) estimate a UK VSL of \$19.9 million, Sandy *et al.* (2001) estimate a UK VSL range of \$5.7 million to \$74.1 million and Siebert and Wei (1994) estimate a UK VSL range of \$9.4 million to \$11.5 million.¹⁷ Our coefficient on non-fatal risk is insignificant and remains so even if we drop fatal risk.

An examination of the coefficient on the exposure risk variable reveals that it is positive in all twelve regressions and significant in six of them. When pollution risk is scaled by value added it is positive and significant in three out of four regressions. Comparing the results with and without the inclusion of fatal and non-fatal risk we can see that the statistical significance of the pollution exposure risk variables is unaffected by the inclusion of fatal and non-fatal risk. However, it can be seen that the magnitude of the pollution coefficient is generally larger in the models that exclude fatal and non-fatal risk, suggesting some correlation between pollution risk and other forms of risk. In

¹⁶ Appendix 3 contains the sample means of all of the variables used in Table 1.

¹⁷ None of these UK studies use our richer LFS dataset.

principle the overlap between pollution risk and fatal and non-fatal injuries should be minimal since the latter measures relate to workplace accidents, the vast majority of which would be unrelated to industrial pollution exposure. In contrast, the pollution risk measures are capturing longer term health risks.

The coefficients and significance of the other explanatory variables are broadly as expected. Full specification results for All Pollutants for *pollution per unit of value added*, *pollution per firm* and *pollution*, respectively are provided in Table 7 in the Appendix. For reasons of space we do not report full results for Heavy Metals, Local Air and Other Pollutants, these are available on request. The default individual is native born; white; male; no qualifications; lives in the South West; works in the agricultural industry, does not work any type of unsociable hours and is a non-manager. The following are broadly negative and significant determinants of wages: female; age squared; health and the majority of our measures of ethnicity. Regional unemployment; physical capital intensity (non-wage value added) and growth in gross value added (industry growth) 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; whether married; whether working in the manufacturing sector. These results are generally as expected (except perhaps the sectoral unemployment rate) and are similar to the majority of compensating wage differential studies.

3.1 Calculating Weekly Wage Premia

We now seek to calculate weekly wage premia associated with working within the five most pollution intensive industries. In order to do this we firstly rank industries in terms of the three exposure measures (for ‘all pollutants’) and then add the three rankings. Industries are then ranked again in terms of this sum of rankings and from this we identify the 5 most pollution intensive industries. We create dummy variables for these 5 industries and interact them with our pollution variables and include them in equation (1) alongside our main pollution variables. This allows us to identify whether the impact of pollution on wages is higher in these industries than across industries overall. In turn, this allows us to estimate weekly wage premia for these industries. Table 2 presents the estimated coefficients on the interactions between dummy variables for the 5 dirtiest industries and pollution variables. We also report the coefficients on fatal and non-fatal risk (all other coefficients are omitted for reasons of space).

[Table 2 about here]

Table 3 presents actual industry level wage premia for our five dirtiest industries in monetary terms. We present the actual weekly wage premium in pounds sterling and the percentage of the weekly wage that this constitutes.

[Table 3 about here]

For *pollution*, if we exclude the Extraction of Oil and Gas (SIC11+12) and SIC (23), that may have large premia for reasons not controlled for in this paper such as unsociable working conditions, the largest wage premia in percentage terms are around 15% for Other Organic Basic Chemicals (SIC2414) and Other Inorganic chemicals (SIC2413). In absolute terms this translates into an increase in the weekly wage of around £50. The remarkably small differences across pollution exposure measures in terms of magnitude or ranking of industries gives us confidence that our three proxies are capturing an element of an individual's pollution exposure albeit indirectly.

Table 3 also provides fatal risk premia, allowing a comparison with pollution premia. Across all 81 industries, the average weekly fatal risk premium ranges from £1.30 to £1.50 (0.54% to 0.63%). The equivalent figures for pollution premia are £0.20 to £0.80 (0.1% to 0.4%) across all 81 industries. Converting to annual figures and multiplying by the total manufacturing labour force of 3,264,343 (2003), provides total annual fatal risk compensation of between £220.7 million and £254.6 million and total annual pollution risk compensation of between £33.9 million and £135.8 million.

4. Conclusions

The compensating wage literature is well established and numerous papers investigate both the causes of 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. After taking care to fully specify our econometric model in light of these arguments our results provide wage premia estimates of one half of one percent across all sectors of the economy although this rose to an average of approximately 15% for workers in one of the five dirtiest industries. Our estimates of the VSL for the UK range between £12 and £19m in 2000 prices. These are consistent with previous UK studies although they are more than double the accepted US estimates. We believe one reason is because the risk of a fatal injury at work is significantly lower in the UK than other countries that have been subject to VSL studies.

The policy implications are clear. Although a reduction in exposure need not have an impact on productivity and efficiency *per se*, an increase in pollution abatement by UK companies should lead to an improvement in working conditions and thus lower levels of sickness absence, reductions in compensation payments etc. Along these lines 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. Following the initial work of this paper it might also be useful in future work to determine which type of emissions correspond better to actual exposure and estimate with those emissions only. This will require a much greater understanding of the health literature.

5. References

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6. Appendix

[Table 4 about here]

[Table 5 about here]

[Table 6 about here]

[Table 7 about here]

Table 1: OLS estimates of the impact of pollution and risk on (log) wages of manual workers (estimated coefficients).

		<i>Pollution per unit of value added</i>		<i>Pollution per firm</i>		<i>Pollution</i>	
		Base	Full	Base	Full	Base	Full
All Pollutants	Pollution	2.26* (1.207)	1.87** (1.124)	89.823*** (32.76)	59.53 (37.08)	0.267 (0.169)	0.114 (0.184)
	Fatal Risk	-	0.012** (0.0064)	-	0.0133** (0.006)	-	0.014** (0.0067)
	Non-Fatal Risk	-	-0.00013 (0.00012)	-	-0.00012 (0.00012)	-	-0.00013 (0.00012)
	R-squared	0.4318	0.4323	0.4315	0.4320	0.4314	0.4320
Heavy Metals	Pollution	27.17 (16.36)	26.521 (16.56)	6910.71*** (1363.44)	6,658.1*** (1,616.6)	8.804 (6.072)	7.494 (6.901)
	Fatal Risk	-	0.0139** (0.0059)	-	0.0135** (0.0057)	-	0.0129** (0.0064)
	Non-Fatal Risk	-	-0.00014 (0.00012)	-	-0.00012 (0.00012)	-	-0.00014 (0.00012)
	R-squared	0.4320	0.4327	0.4327	0.4333	0.4317	0.4322
Local Air	Pollution	2.407* (1.259)	1.946* (1.117)	89.11*** (29.28)	56.32* (33.427)	0.258 (0.175)	0.0884 (0.185)
	Fatal Risk	-	0.0126* (0.0064)	-	0.0135** (0.0065)	-	0.0142** (0.0067)
	Non-Fatal Risk	-	-0.00013 (0.00012)	-	-0.00012 (0.00012)	-	-0.00013 (0.00012)
	R-squared	0.4317	0.4322	0.4314	0.4320	0.4313	0.4319
Other Pollution	Pollution	2.395* (1.217)	1.937* (1.109)	86.209** (28.52)	54.81* (32.74)	0.258 (0.165)	0.0959 (0.177)
	Fatal Risk	-	0.0123* (0.0064)	-	0.0134** (0.0065)	-	0.0141** (0.0068)
	Non-Fatal Risk	-	-0.00013 (0.00012)	-	-0.00012 (0.00012)	-	-0.00013 (0.00012)
	R-squared	0.4318	0.4323	0.4315	0.4320	0.4313	0.4319
Observations		52894		52894		52894	

The base model contains a full set of controls but excludes fatal and non-fatal risk.

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

The risk coefficients are based on a denominator of 100,000 workers.

Table 2: OLS estimates of the impact of pollution on (log) wages in the top five dirty industries

(all pollutants only, estimated coefficients and standard errors)

	<i>Pollution per unit of value added</i>		<i>Pollution per firm</i>		<i>Pollution</i>	
Total	0.591**	(0.273)	24.37	(16.79)	-0.113	(0.147)
Extraction of Petrol & Gas (SIC11 +12)	226.88***	(26.10)	21,417.9***	(2,554.9)	16.910***	(1.781)
Coke ovens, refined petrol & nuclear (SIC23)	14.32***	(0.849)	1,742.5***	(94.35)	6.867***	(0.411)
Structural Clay Products (SIC264)	6.048***	(1.605)	4,429.78***	(1,067.3)	18.76***	(4.440)
Other Inorganic Chemicals (SIC2413)	16.767***	(3.033)	10,975.3***	(2,022.31)	38.54***	(7.220)
Other Organic Basic Chemicals (SIC2414)	23.60***	(3.86)	2,905.6***	(477.56)	17.65***	(2.880)
Fatal Risk	0.0194***	(0.005)	0.0194***	(0.005)	0.021***	(0.005)
Non-Fatal Risk	-0.0002	(0.0001)	-0.0001	(0.0001)	-0.0002	(0.0001)
Observations		52894		52894		52894
R-squared		0.43		0.43		0.43

Clustered standard errors in parentheses, ***, ** and * denote significance at 99%, 95% and 90%, respectively. Results for heavy metals, local air pollution and other pollution are available from the authors upon request.

Table 3: Wage premia in dirty industries (Pounds £ per week and as a percentage of the average weekly wage in each industry)

	<i>Pollution per</i>	%	<i>Pollution per</i>	%	<i>Pollution</i>	%
	<i>unit of value</i>		<i>firm</i>			
	<i>added</i>					
SIC11+12	118.2	28.2	119.2	28.4	125.9	30.0
SIC23	87.5	24.5	87.4	24.5	93.9	26.3
SIC264	15.6	5.9	17.2	6.5	17.4	6.6
SIC2413	49.2	16.5	45.1	15.1	50.2	16.8
SIC2414	51.3	15.2	43.8	13.0	51.1	15.1
Ave. for all 81 industries	0.8	0.4	0.2	0.1	0.2	0.1
Fatal risk premium	1.3	0.54	1.4	0.60	1.5	0.63
Ave. for all 81 industries						

This table calculates how much lower fitted wages would be in these industries if pollution were equal to zero. Wage premia 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 premia calculated using the mean-level of pollution across industries are, inevitably, smaller and are available upon request. The final row of the table calculates how much lower fitted wages would be in these industries if fatal risk were equal to zero (it differs across exposure measure only because the estimated coefficient on fatal risk differs slightly in each model).

Table 4: UK Environment Agency 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 administration
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		

Table 5: 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		
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

Table 6. Table of Sample Means.

	Mean	S.D.		Mean	S.D.
Gross Weekly Pay	240.85	114.71	Female ^A	0.21	0.41
Total Emissions (<i>Pollution</i>) see eq'n (2)	0.01	0.03	Foreign Born ^A	0.05	0.22
Emissions/GVA (<i>Pollution per unit of value added</i>) see eq'n (3)	0.001	0.005	White ^A	0.96	0.18
Emissions/ N ^o Firms (<i>Pollution per firm</i>) see eq'n (4)	0.00001	0.0001	Black Caribbean ^A	0.01	0.09
Fatal Risk (industry level fatalities per 100,000 workers)	1.57	1.91	Black African ^A	0.003	0.05
Non-Fatal Risk (industry level non-fatal injuries per 100,000 workers)	184.35	119.16	Black Other ^A	0.001	0.03
Poor Health ^A	0.08	0.27	Indian ^A	0.01	0.11
Union Member ^A	0.37	0.48	Pakistani ^A	0.004	0.06
Worked for Firm>5 yrs ^A	0.47	0.50	Bangladeshi ^A	0.001	0.03
Shift Work ^A	0.30	0.46	Chinese ^A	0.001	0.03
Evening Work ^A	0.17	0.38	Other Non-White ^A	0.01	0.08
Night Work ^A	0.20	0.40	Married ^A	0.62	0.49
Growth GVA	-0.75	10.69	Observed in 1996 ^A	0.17	0.37
PCI	0.75	0.08	Observed in 1997 ^A	0.16	0.37
Firm Size	0.56	0.28	Observed in 1998 ^A	0.16	0.37
Agriculture ^A	0.0003	0.02	Observed in 1999 ^A	0.16	0.36
Fishing ^A	0.0001	0.01	Observed in 2000 ^A	0.14	0.35
Mining ^A	0.01	0.09	Observed in 2001 ^A	0.11	0.31
Manufacturing ^A	0.41	0.49	Observed in 2002 ^A	0.10	0.30
Utilities ^A	0.01	0.10	North ^A	0.07	0.25
Construction ^A	0.11	0.31	Yorkshire ^A	0.10	0.30
Wholesale & Retail ^A	0.11	0.32	North West ^A	0.10	0.30
Hotels and Restaurants ^A	0.04	0.19	East Midlands ^A	0.09	0.28
Transport & Comms ^A	0.13	0.33	West Midlands ^A	0.11	0.31
Real Estate & Business ^A	0.05	0.21	East Anglia ^A	0.04	0.20
Education ^A	0.03	0.18	South East ^A	0.23	0.42
Health & Social Work ^A	0.06	0.24	South West ^A	0.08	0.27
Other Sector ^A	0.04	0.21	Wales ^A	0.05	0.22
Age	39	12.14	Scotland ^A	0.10	0.30
Degree as Highest Qual ^A	0.05	0.23	Northern Ireland ^A	0.03	0.17
A1 level as Highest Qual ^A	0.39	0.49	Regional U Rate	0.09	0.02
O level as Highest Qual ^A	0.15	0.36	Manager ^A	0.00002	0.004
Other as Highest Qual ^A	0.21	0.40	N	52894	
No Qualifications ^A	0.80	0.38			

^A denotes a 0/1 dichotomous dummy variable. SD refers to the standard deviation. Equivalent full specification results

for heavy metals, local air, and other pollution are available on request.

Table 7: OLS (log) Wage equation for all pollutants, full specification (1995-2003)

Variable	<i>Pollution per unit of value added</i>		<i>Pollution per firm</i>		<i>Pollution</i>	
	Coefficient	SE	Coefficient	SE	Coefficient	SE
Emissions	1.875	1.124	59.536	37.089	0.114	0.185
Fatal Risk	0.012	0.006	0.013	0.007	0.014	0.007
Non-Fatal Risk	-0.0001	0.0001	-0.0001	0.0001	-0.0001	0.0001
Health	-0.085	0.006	-0.085	0.006	-0.085	0.006
Union	0.101	0.009	0.101	0.009	0.101	0.009
Tenure	0.086	0.014	0.086	0.014	0.087	0.014
Shift work	0.078	0.011	0.078	0.011	0.078	0.011
Evening work	0.026	0.005	0.026	0.005	0.026	0.005
Night work	0.099	0.005	0.099	0.005	0.099	0.005
Industry growth	0.001	0.0004	0.001	0.0004	0.001	0.0004
PCI	0.144	0.100	0.136	0.100	0.138	0.100
Firm Size	0.141	0.043	0.139	0.042	0.144	0.043
Age	0.057	0.007	0.057	0.007	0.057	0.007
Age squared	-0.001	0.0001	-0.001	0.0001	-0.001	0.0001
Degree	0.293	0.015	0.294	0.015	0.294	0.015
A level	0.168	0.007	0.168	0.007	0.168	0.007
O level	0.074	0.011	0.074	0.011	0.074	0.011
Other Qualification	0.046	0.007	0.046	0.007	0.046	0.007
Female	-0.284	0.011	-0.284	0.011	-0.284	0.011
Foreign Born	0.026	0.010	0.026	0.010	0.026	0.010
Black Caribbean	-0.044	0.018	-0.044	0.018	-0.044	0.018
Black African	-0.102	0.044	-0.102	0.044	-0.102	0.044
Black Other	0.072	0.054	0.071	0.054	0.071	0.054
Indian	-0.150	0.020	-0.150	0.020	-0.150	0.020
Pakistani	-0.210	0.030	-0.210	0.030	-0.210	0.030
Bangladeshi	-0.532	0.098	-0.532	0.098	-0.532	0.098
Chinese	-0.127	0.059	-0.127	0.059	-0.127	0.059
Other ethnic	-0.047	0.021	-0.047	0.021	-0.047	0.021
Married	0.054	0.006	0.054	0.006	0.054	0.006
Unemployment Rate	0.512	0.384	0.511	0.385	0.513	0.385
Manager dummy	0.760	0.022	0.758	0.022	0.756	0.022
Constant	-0.069	0.143	-0.069	0.143	-0.073	0.143
Region dummies	YES	YES	YES	YES	YES	YES
Sector dummies	YES	YES	YES	YES	YES	YES
Year dummies	YES	YES	YES	YES	YES	YES
	0.432		0.432		0.432	
N	52894		52894		52894	

The default individual in our regressions is native born; white; male; that has no qualifications; lives in the South West; works in the agricultural industry, does not work any type of unsociable hours and is a non-manager.