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Abstract

This paper estimates workers' demand function for job safety using the 1973 British General Household Survey data. The estimation employs Rosen's two-stage procedure. The main difference between our study and those done in the past is that we estimate hedonic price equations with data sets from two separate markets. Our approach overcomes the usual identification problems associated with the application of Rosen's method.

The estimation shows that there is a significant wage compensation for job risk in the UK. The willingness-to-pay for a 1/100,000 increase of annual job fatal accident rate from our estimated workers' demand function is about £6 in 1973 price. The estimation of demand function for safety also enables us to derive workers' willingness-to-pay for non-marginal change of job risk, and therefore can be used for cost-benefit analysis on projects involving such non-marginal changes.

1 Introduction

For the last two decades, we have witnessed a rapid improvement in workplace safety in the UK. The on-the-job fatal accident rate has fallen from 4.6 per 100,000 workers per year in the late 60's to about 1.6 per 100,000 employees per year in the beginning of 90's. Despite this significant improvement, the recent statistics published by the Health and Safety Executive show that each month, about 29 British workers are killed by on-the-job accidents, and 12,000 are seriously injured (involving absence from work of more than three days). These figures remind us that safety hazards continue to accompany modern work processes. The existence of these accidents is often used to justify the need for further strengthening of government safety policies. On the other hand, the implementation of some rigid safety standards could impose exceptionally high costs on firms and make it prohibitive for them to carry on business[1]. The optimal policy therefore has to be made based on proper cost-benefit analysis. To carry out such a cost-benefit analysis, we need to know workers' willingness-to-pay (WTP) for safety improvement.

One way of estimating workers' WTP for safety improvement is to use labour market information. Conventional economic theory predicts that under perfect competition a worker will require wage compensation for doing a risky job, and the firm offering the job will be penalised by a wage premium. As

[1] For example, the estimated cost increase of oil rig operation was 10% to 15% following the adoption of the new legislated safety measures after the 1988 Piper Alpha oil rig disaster in the North Sea (*Financial Times*, April 28, 1989).

workers differ in their risk attitudes and firms vary in their costs of reducing accidents, the labour market equilibrium results a series of wage/risk loci: the hedonic wage functions (see Rosen, 1986). Past studies of compensating wage differentials for job risks have mainly concentrated on estimating a hedonic wage function, and used the wage-risk slope as the estimate of workers' WTP for marginal changes of job risk (see Viscusi 1993, for a detailed survey). However, as new safety standards and measures often involve non-marginal changes of workplace job safety levels, it is the estimation of the WTP for non-marginal change of safety level that is widely sought.

In order to estimate a worker's WTP for a non-marginal safety improvement, it is necessary to know his/her demand function for safety. Rosen (1974) was the first to demonstrate that even without knowing the underlying distribution of consumers' tastes and firms' technologies, it is still possible to estimate the supply and demand curves for a hedonic good following his two-stage procedure. Biddle and Zarkin (1988) adopted such a procedure and performed a joint estimation of the market income-risk locus and the optimum conditions for utility maximization. However, recent econometric studies by Bartik (1986) and Epple (1987) have shown that the estimation of hedonic systems using single labour market data is likely to be biased.

In this paper, we adopt a modified Rosen two-stage procedure to estimate a worker's demand function for safety. The novelty of our estimation is to treat the labour markets in the north and the south of England as two separate markets. So in contrast to Biddle and Zarkin, we estimate two hedonic wage functions for the north and the south, respectively. As shown below, the use of two estimated market equilibrium wage curves provides us with the necessary information to identify workers' underlying demand functions for safety.

In section 2, a simple model of hedonic equilibrium and the general problems associated with the estimation of demand and supply functions for hedonic goods are discussed. In section 3, we specify our empirical models and estimation procedures. Section 4 presents the estimation results. We provide our concluding remarks in section 5.

2 The Theoretical Model and Identification Problems

The theoretical model we employ in this section was established by Rosen (1974) and Thaler and Rosen (1976). In Thaler and Rosen (1976), the labour market transactions were treated as tied sales. Workers sell their labour, and at the same time they consume the non-pecuniary aspects of their jobs. Firms must pay for labour time as well as compensations for the unpleasant or dangeous aspects of their jobs. So if we assume that p denotes one such aspect, the job risk (in this paper, the only type of job risk we consider is the on-the-job death risk), and $\mathbf{x}$ represents a vector of all other characteristics of jobs, the equilibrium market wage rate w is a function of p and $\mathbf{x}$:

$$w = w(p, \mathbf{x}) \tag{1}$$

In a competitive market, $w(p, \mathbf{x})$ is given for both workers and firms. Assuming that individual workers' utility functions are: $U(c, p, \mathbf{d})$, where c is the total consumption with a normalised price of unity, and $\mathbf{d}$ is a vector of other individual parameters, a worker's optimal decision when choosing types of jobs vs wages can be summarized as the following maximization problem:

$$\begin{aligned} &\underset{c,p}{Maximise} \; : U = U(c,p,\mathbf{d}) \\ &subject \quad to : c = y + w(p,\mathbf{x}), \end{aligned} \tag{2}$$

where y is non-labour income.

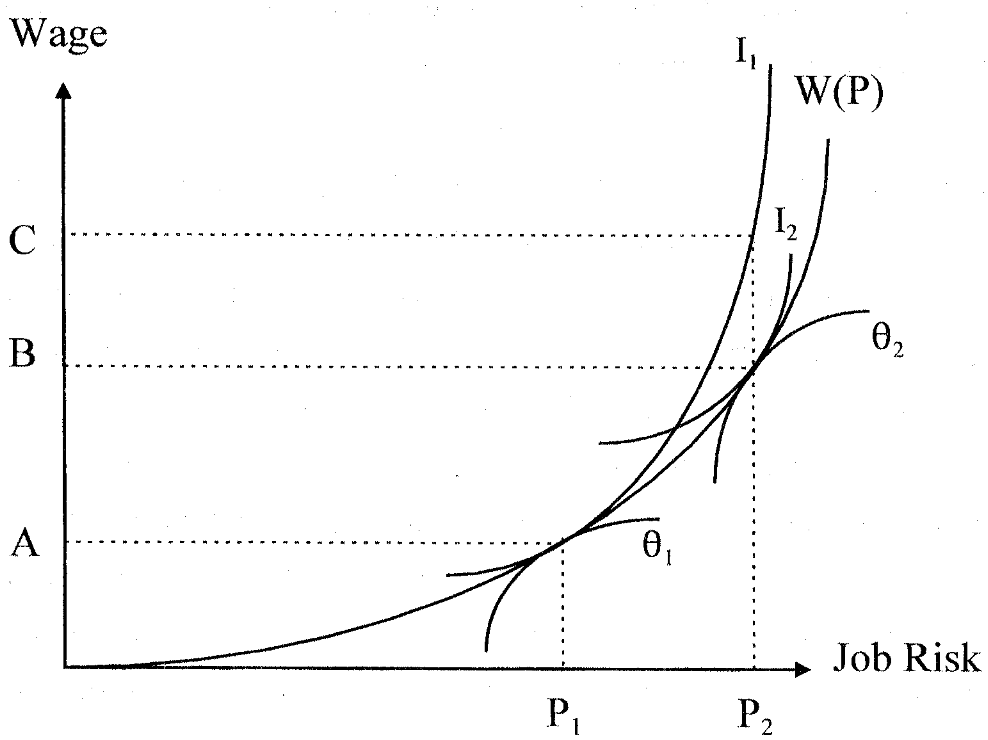
Solving this maximization problem produces a demand function for job safety as below:

$$w_p = -\frac{U_p(y + w(p,\mathbf{x}), p, \mathbf{d})}{U_c(y + w(p,\mathbf{x}), p, \mathbf{d})} = D(y + w(p,\mathbf{x}), p, \mathbf{d}) \tag{3}$$

The same analysis can be applied to firms, when their cost functions are given. The market equilibrium is established when the total supply of jobs equals the total demand for them, as well as the supply of each job characteristic equals the demand for it.

Since the observed $w(p,\mathbf{x})$ is a joint envelope of a family of workers' value functions and a family of firms' offer functions which generate it, it has no direct implications for the structure of the underlying demand and supply functions. This can be best illustrated using Figure 1, in which we show one market wage locus *w(p)*, and two workers' (1 and 2) indifference curves I_1 and I_2. θ_1 and θ_2 are the iso-profit curves for firm 1 and 2, respectively. Worker 1's true required compensation for a change of job risk from P_1 to P_2 is AC. However, if we measure the change along the hedonic wage function, the estimated required compensation is AB which under-estimates the true required compensation[2].

Figure 1



Following Rosen (1974), the empirical estimation of the demand and supply functions can be accomplished without the derivation of the exact

[2] It is also straight forward to see that the hedonic wage function will over-estimate the worker's required compensation for risk increase when the indifference curve is concave from below.

analytical relation between the structural parameters of interest and parameters of the market wage function. A two-stage procedure can be employed to estimate demand and supply functions simultaneously. First, the market wage function (1) can be estimated by regressing observed wages on all job characteristics using the functional form derived from some "best fit" statistical criterion. The partial derivative with respect to p of $w(p,\mathbf{x})$ is then obtained:

$$w_p = w_p(p,\mathbf{x}) \tag{4}$$

Second, the resultant w_p, is used as if it were the observed market "price" of p, and the estimation of (3) is carried out in the same manner as the estimation of demand functions for ordinary goods in the market. The standard demand and supply interaction problem can be solved by using variables characterizing individual firms as the appropriate instruments for p and $\mathbf{x}$ in (3).

Several problems have been noted with the estimation of hedonic demand and supply functions using Rosen's approach (See Epple 1987, and Bartik 1987). First, there is a simultaneity problem associated with the estimation of hedonic demand and supply systems. However, this is not due to the ordinary demand and supply interaction, as the hedonic price function is assumed to be given to both consumers and firms. The possible nonlinearity of the hedonic price function allows consumers to choose both quantities and marginal prices simultaneously[3]. For example, worker 1 in Figure 1 chooses p_1 and the corresponding price of safety (at level p_1) $w'(p_1)$ simultaneously. Consequently, the OLS estimation of (3) must be biased when some unobserved personal characteristics are correlated

[3] Rosen (1974) pointed out that such a nonlinearity will occur if a hedonic good cannot be untied without involving extra cost.

with p. Secondly, the optimization means that consumers with a special preference for some characteristic of a good will buy it from the firm with the least cost of producing it. This is shown in Figure 1 as the more risk averse Worker 1 systematically matches with Firm 1 which has a cheaper marginal cost to produce safety and hence supplies the safer job. Therefore, firm characteristics are not appropriate instruments for p, since they will generally be correlated with the unobserved workers' tastes embodied in the error terms of demand equations.

To achieve consistent estimation of the system, we need factors which exogenously shift the market wage locus but remain uncorrelated with unobserved individual characteristics. They can be found when multi-market data are available. This is because we can assume that wage functions differ across markets due to different distributions of worker tastes and firm safety productivities, but workers' demand functions for safety are invariant across markets. So with multi-market data, the market specific variables in the marginal wage equation will provide the required independent variation.

3 The Empirical Model and Estimation Method

In our empirical study, we assume that individual workers possess a GCES utility function:

$$U = [\mu p^{b_1} + c^{b_2} + \mathbf{d}]\phi \tag{5}$$

where p represents on-the-job annual death risk; c is the total consumption; $\mathbf{d}$ is a vector of other variables in the utility function, which are not directly related to p

and c; bs are parameters; μ denotes the latent parameter of individual attitudes towards risks, and ϕ is an error term. We also assume:

$$\mu = \beta \mathbf{z} + \eta \tag{6}$$

where $\mathbf{z}$ includes exogenous variables which affect a worker's risk aversion, and η is a random variable.

Suppose that the market wage function $w(p, \mathbf{x})$ has the following semi-log form:

$$\log w = \alpha_0 + \alpha_1 p + \alpha_2 \mathbf{x} + \varepsilon \tag{7}$$

According to Section 2, the demand function is:

$$w_p = -\frac{U_p}{U_c} = -\frac{b_1 \mu p^{b_1 - 1}}{b_2 c^{b_2 - 1}} = -\frac{b_1 \beta \mathbf{z} p^{b_1 - 1}}{b_2 c^{b_2 - 1}} \tag{8}$$

Our estimation procedure involves two stages: first, we estimate two separate wage equations for two markets (the north and the south); second, using the constructed w_p from those two equations, we estimate the nonlinear demand function (8).

The optimization in our model shows that workers choose wages and job risk simultaneously; job risk is an endogenous variable. In particular, if safety is a normal good, the job risk will be correlated with the unobserved earning ability variables in the error term of the wage equation. Furthermore, as the available data for job risk are generally occupational or industrial level data, they are most likely to suffer a measurement error problem[4]. So the two-stage least square method is employed in our estimation of the wage equations with risk variable instrumented.

4 Data and Estimation Results

We use the British 1973 GHS as our main database, which includes information on households' income and personal characteristics. The risk data are the on-the-job death risk measured as the occupational death rate per thousand workers per year minus the probability of death expected given the occupational age structure[5]. The figure is an average over the years 1970-72. We combined these two data sets by 223 standard occupation groups, classified by Office of Population Censuses and Surveys (OPCS) in 1970. This set of risk data is still by far one of the best available in the UK. The 1973 GHS is therefore chosen to best match the risk data.

Our samples are restricted to male head of households who work over 20 hours a week and live in the north or the south of England[6]. We assume that the

[4] The more extensive discussions of this endogeneity problem of the job risk variable and the estimation of the wage differential for job risks with the simultaneous equations model can be found in Hwang et al (1992) and Siebert and Wei (1994).

[5] This is the Accrisk data constructed by Marin and Psacharopoulos (M-P) (1982), based on the occupational fatality information collected by the Office of Population Censuses and Surveys (OPCS).

[6] We define the north and the south based on the 11 regional divisions of GHS. The north includes: Northern, Yorks and Humberside, and North-west. The south includes: Great London, South-east and South-west.

north and the south are two distinctive labour markets. Evidences of regional labour market segregation in the UK can be found in many previous studies, notably Blackaby and Murphy (1990), and Blanchflower and Oswald (1994).

The dependent variable for both wage equations is the logarithm of annual wage rate (*logw*). The logarithm of "weeks of working a year" (*lwkswk*) is included as an independent variable, so as to give a weekly earnings construct, since hourly earnings are not available in the GHS.

Apart from *lwkswk*, **x** includes normal human capital variables: age left full-time education (*edlgag*); three dummies for educational qualifications (*ed1* for higher qualifications; *ed2* for A-level equivalent qualifications; *ed3* for O-level equivalent qualifications); years of working experience (*expe* = *age* - *edlgag*) and its square (*expe2*); years of working on present job (*tenure*) and *tenure* square. In addition, we also use the Goldthorpe and Hope occupational desirability index (*occr*)[7], percentage of union coverage in the industry of the respondent (*union*), and dummies for whether working overtime (*otime*), marital status (*married*) and industry (10 industries).

Our **z** is meant to capture individual heterogeneity in risk attitudes. We select following variables: *edlgag*, *expe*, *tenure*, *occr*, *married*, numbers of dependant children (*dep*), wife's age left full-time education (*wiflsch*), numbers of moves in the past five years (*nmoves*); and dummies for whether owning a house

[7] We included this index to allow for non-pecuniary aspects of jobs which are not (or are only distantly) related to risk of death. This index gives a numerical ranking to each of our occupation (223 categories) based on a survey of people's evaluation of their "social standing" (see Goldthorpe and Hope, 1974).

(*ownh*), whether living in the north (*north*). The means and the standard deviations of the main variables are listed in Table 1.

4.1 The estimates of the Wage Equations

Our specification of the wage equation is very similar to that of M-P's (1982). However, in contrast to M-P, we treat job risk as an endogenous variable. The estimated results with the instrumental variables method for the two wage equations are presented in Table 2.

The results in Table 2 show that the coefficients on all the conventional human capital variables have kept their meanings. A positive coefficient on *occr* shows that highly rated occupations also are the ones with high pay.

Our main interest must lie in those coefficients associated with job risk. For both wage equations, the coefficients on p are positive and significant: indicating a positive wage compensation for job risk. The estimated compensating wage differentials for job risk for an average person in the north is £6.8 per year for an extra 1/100,000 annual risk of death, and £5.1 for an average person in the south in 1973 prices[8]. Following Thaler and Rosen (1978), this gives the estimated value of a statistical life £0.68m in the north and £0.51m in the south. The fact that the compensating wage differential for job risk is lower in the south than that in the north may be due to the much lower average job risk facing workers in the south (see mean job risk figures in Table 1) and the nonlinear wage

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[8] The compensating wage differential for job risk is calculated as the mean value of $\frac{\partial \log w}{\partial p} w$.

Table 1: Means and Standard Deviations of the Main Variables[a]

	North		South	
Variables	Mean	Standard Deviation	Mean	Standard Deviation
logw	7.451	0.435	7.629	0.473
p (death risk:1/100,000)[b]	17.364	107.97	-6.943	89.516
edlgag (years of age)	15.251	2.054	15.965	2.701
ed1	0.050	0.217	0.090	0.286
ed2	0.127	0.333	0.140	0.347
ed3	0.224	0.417	0.160	0.367
expe (years)	27.120	12.808	26.338	13.373
tenure (years)	11.233	10.620	11.709	10.560
lwkswk	3.901	0.198	3.918	0.199
occr	41.877	13.977	47.031	16.290
union	29.8%	0.165	27.9%	0.141
otime	47.7%	0.500	39.6%	0.489
married	93.5%	0.246	92.7%	0.260
totwe (£1,000)	0.6295	1.2961	0.7428	0.8782
dep (no. of dependents)	2.013	1.341	1.875	1.253
nmoves (no. of moves)	0.383	1.051	0.517	1.280
ownh (owns house)	12.0%	0.329	12.5%	0.331
wiflsch (years of age)	13.558	4.271	13.641	4.672
Sample Size	1171		1403	

Source: 1973 GHS, and M-P (1982).

a. The analysis also used 10 industry dummies in the wage equation, and the wife's income (Wifinc), number of cars owned (Cars) and 4 dummies of father's socio-economic group as instruments for the risk variable.

b. This is the variable Accrisk from M-P (1982), which is measured as an average of the 1970 - 72's occupational fatality (collected by the OPCS) minus the probability of death expected given the occupational age structure. So negative values are presented.

Table 2: The Instrumental Variable Estimation of the Wage Equations

The Dependent Variable: *logw*				
	North		South	
Independent Variables	Coefficients	t-statistic	Coefficients	t-statistic
intercept	-0.454	-0.650	-0.037	-0.082
p^a	0.004	3.355	0.002	2.600
lwkswk	1.153	17.839	0.958	19.394
expe	0.025	5.206	0.033	9.692
expe2	-0.0004	-4.986	-0.0006	-9.359
edlgag	0.200	2.928	0.292	6.904
edlgag2	-0.004	-2.261	-0.007	-6.337
ed1	0.114	1.400	0.223	4.979
ed2	0.101	1.925	0.085	2.837
ed3	0.042	1.140	0.067	2.348
tenure	0.006	1.253	0.010	2.402
tenure2	-0.0001	-0.967	-0.0002	-1.578
occr	0.018	6.933	0.014	8.208
otime	-0.026	-0.772	0.010	0.468
union	0.011	3.922	-0.0008	-0.398
married	0.071	1.356	0.036	0.967
Industry dummies	included		included	
R^2	0.101		0.473	
Sample size	1171		1403	

Source: 1973 GHS and M-P (1982).

a. The instruments for *p* include all independent variables in the wage equation plus those mentioned in Table 1 (a).

curves in job risk. It is worth noting that both figures are much higher than the estimates of Marin and Psacharopoulos (1982) on similar data sets with the single wage equation model and the OLS technique. This confirms that both the omitted earning ability variables (which are negatively correlated with job risk, if job risk is an inferior good) and the measurement error of p bias the coefficient of the job risk downward in the single equation model.

4.2 The Estimation of the Demand Equation

We use the estimated marginal prices for job risk in the north and the south as the observed market prices for job risk to estimate the demand function for safety (8). The results are listed in Table 3.

In Table 3 the estimated coefficients show that a person with more dependents asks for higher compensating wage differentials for job risk. This is the case when having more dependents means more responsibility and hence more risk aversion. Higher education level and longer tenure are also associated with more compensating wage differentials. This illustrates that people whom have invested more in their own human capitals are more cautious and require higher compensation to take risks. It also indicates that able and wealthier people need more wage compensation for job risk --- safety is a normal good. Such a fact is further supported by the positive association of both social ranking of occupation and total household income with compensating wage differentials.

Table 3: The Estimation of the Demand Function for Job Safety

The Demand function : $w_p = -\frac{b_1(\beta z)p^{b_1-1}}{b_2 c^{b_2-1}}$

Z Variables	Coefficients[a]	t-statistic
intercept	-3.174	3.523*
dep	-0.364	5.353*
ownh	-0.042	0.343
edlgag	-0.045	1.833
married	0.825	2.431**
wiflsch	0.018	1.162
expe	0.019	3.104*
occr	-0.030	6.731*
nmoves	0.059	1.462
ten	-0.026	4.752*
north	-3.062	6.769*
b_1 [b]	0.963	30.996*
b_2	0.271	26.364*
Adjusted R^2	0.7317	
Sample size	2,574	

Source: 1973 GHS and M-P's Accrisk data.

a. All coefficients have been multiplied by 1,000 except b_1 and b_2.

b. We use p+100 instead of p in the estimation to overcome the problem caused by the negative value of p in the function p^{b_1}.

* significant at 1% level; ** significant at 5% level

Our results also show that people living in the north demand more compensation for job risk than people living in the south. Furthermore, a married person or a person with more working experience receives less compensation for job risk. These results are hard to explain.

One advantage of our estimation of the demand parameters is that we can use it to derive a worker's required compensation or willingness to pay for a non-marginal change of the job risk. Given our GCES utility function (7), the willingness to pay (W) of a worker for a decrease of the annual job risk (δp) is:

$$W = c - \left[\mu\left(p^{b_1} - (p - \delta p)^{b_1}\right) + c^{b_2}\right]^{1/b_2} \tag{9}$$

The compensation, C, a worker requires for an increase of the annual job risk (δp) is:

$$C = \left[\mu\left(p^{b_1} - (p + \delta p)^{b_1}\right) + c^{b_2}\right]^{1/b_2} - c \tag{11}$$

In Table 4 we list the willingness-to-pay (WTP) and required compensation figures for 1/100,000, 50/100,000, 100/100,000 changes of job risk from the mean.

Table 4. Some Estimates of workers' WTP and Required Compensation

	Changes of Annual Job Risk		
	1/100,000	50/100,000	100/100,000
Willingness-to-pay	£6.02	£293.05	£573.26
Required Compensation	£6.02	£310.47	£641.03

Two facts are shown in Table 4. First, workers' WTP decreases for successive reductions in job risk, while the compensation they require, increases for successive increments of job risk. Secondly, workers' required compensation for an increase of job risk is higher than workers' WTP for an equal amount of decrease in job risk. Together, they confirm that the use of the hedonic wage equation to estimate workers' WTP or required compensation for non-marginal change of job risk is likely to incur errors.

5 Conclusion

The estimation of the compensating wage differential for job risk has been frequently carried out with a market wage function. Such an estimation can only provide the information on workers' willingness to pay for a marginal change of their job risks. This paper has attempted to recover the underlying workers' demand for safety. The estimation of a demand function permits us to test workers' willingness to pay for a non-marginal change in job risk. Furthermore, we estimated wage equations for two separated labour markets and used the information of these two markets to identify the demand function for safety. This method overcomes the problems associated with the estimation of hedonic demand functions using single market data recently raised by many researchers.

Our empirical results show that a substantial wage compensation is demanded for job risk in UK labour markets. The estimated value of a statistical life reaches £0.6m in 1973 prices. Our results also verify that safety is a normal good.

Several pitfalls remain with the current investigation. First, we used occupational risk measure as the proxy for the risk facing individual workers, which may cause not only the usual measurement error problem for the estimates but also possible biases in t-statistics pointed by Moulton (1988). As far as we know such problems cannot be tackled until reliable individual level job risk measure has been found. Secondly, the selection of functional forms for the wage equation remains arbitrary to a certain extent.

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