CENTRE FOR LABOUR MARKET AND SOCIAL RESEARCH
UNIVERSITY OF AARHUS AND THE AARHUS SCHOOL OF BUSINESS

Worker and Plant Wages: Estimates from a Multi-Level Model

Paul Bingley and Niels Westergård-Nielsen

Working Paper 96-10
October 1996

Published by

Centre for Labour Market and Social Research
Science Park Aarhus
Gustav Wieds Vej 10C, 8000 Aarhus C, Denmark

Editor: Henning Bunzel

Copyrights:

ISSN 0908-8962

Worker and Plant Wages: Estimates from a Multi-Level Model

Paul Bingley and Niels Westergård-Nielsen

Working Paper 96-10
October 1996

JEL classifications: C23, J31, J41

Keywords: Establishment wage differentials, multi-level models

Abstract

Empirical studies of wage determination have focussed mainly on either worker supply side factors or employer demand side considerations. Theory puts forward several reasons why employers may pay a premium to all workers rather than a selected few, based upon ideas of limited information, and employer, worker and job heterogeneity. Coherent modelling of both sides of the market is crucial in assessing the nature and importance of employer pay policy. A multi-level random effects model is estimated on a Danish representative matched panel of 1400 private sector workplaces and all employees over 11 years. We find strong evidence of firm-specific pay policy in the form of establishment wage differentials after having controlled for worker and match effects. There is support for monitoring cost driven efficient labour contracts, compensating differentials and sorting/matching models, but no support for models of rent sharing and internal labour markets. Furthermore, we are able to decompose the variance in log wage according to observables (20%), unobserved heterogeneity among workers (38%), workplaces (26%) and worker-workplace matches (6%) leaving 10% unaccounted for

Acknowledgement

Financial support from the Danish National Research Foundation is gratefully acknowledged. The paper has benefited from the comments of Richard Blundell, Tor Eriksson, Francis Kramarz, Gauthier Lanot, Lars Muus, George Neumann and seminar participants in Amsterdam, Austin, Evanston, Helsinki, London, Washington and Århus. Remaining errors are our own.

Addresses

N. Westergård-Nielsen, Aarhus School of Business and CLS, Science Park Aarhus, Gustav Wieds Vej 10, DK-8000 Århus C, Denmark, e-mail: nwn@cls.dk

1. Introduction

Employer wage differentials are important components of individual wage/remuneration inequality. The size and origin of these differences has consequences for the effectiveness of labour market policies, both in terms of inequality and efficiency outcomes. There are several reasons why different employers pay different wages to workers with apparently the same abilities. Or in other words, employers pay a premium to all workers rather than selected individuals. The various theories are based upon ideas of limited information and employer, worker and job heterogeneity. Labour market policy implications differ markedly depending upon the size and origin of these demand induced firm differentials.

Danish labour market experience can contribute valuable empirical evidence to the theoretical debate. The Nordic countries have been known in the past for their centralised wage bargaining (Jackman, 1989). However, Danish wage setting has always been the least centralised of the Nordic countries[1] and since the 80's firm level agreements have become increasingly common. It has yet to be shown what impact this has had on individual and establishment wage dispersion (see Lindbeck, 1993).

In its most extreme form, a centralised wage bargaining system means that employees receive a wage according to a fixed scheme that is common to all firms, only allowing for modest compensating differentials. This would leave little room for a firm specific wage policy. In regression terms this implies that the wage could be explained by characteristics of individuals and jobs, observed and unobserved. Furthermore, workers could only gain by moving firm if they at the same time were promoted. Alternatively, if there is a substantial element of firm-specific wage determination we would expect that worker characteristics can only explain a small part of the wage dispersion and workers could obtain different wage rates for similar jobs in other firms. The result is search and subsequent worker mobility.

Gross turnover rates for Danish private sector workers (24% year-on-year) indicate that the latter picture is the most relevant. These figures are similar to those found for the US (Davis and Haltiwanger, 1993) and France (Abowd, Kramarz and Margolis, 1996) for example. Danish workers have very little protection against being fired, and they may in principle be dismissed without notice. This is unique in Europe but similar to the US. Only white collar workers are

1. Relative firm size distributions contribute to this. Danish firms have the largest average size, and only Finland has a greater share of employees in large firms (500+ employees). See Eurostat (1992) for details and a broader perspective.

entitled to extended notice according to seniority. There also exists a relatively generous unemployment insurance system, with high replacement ratios and extended benefit periods. This system is not experience rated, and consequently employers face no direct cost when they fire workers. All of these factors have a definite impact on the mobility pattern.

A number of recent papers concerning the labour markets of European countries have discussed the effects of wage dispersion on unemployment (Calmfors and Driffill, 1988; Rowthorn, 1992). More centralised wage bargaining is shown to decrease wage dispersion, increase employment and lower inequality. Minimum wage legislation and high replacement ratios may distort efficient labour contracts (OECD, 1993). However, these arguments are supported only by fairly aggregate data. There is a need for evidence to be provided at the employer level.

In summary the aim of this paper is to estimate the size of demand induced firm wage differentials, while consistently accounting for individual worker supply wage determinants. In lieu of firm-level economic information we are able to provide some limited evidence for competing theories of wage determination. The next section places the current work in the context of the empirical and theoretical literature on establishment and worker wage dispersion. Section three presents the main features of the data, and four motivates the econometric framework applied. Section five presents results and finally we conclude.

2. Literature

Excellent surveys of the literature on demand side theories of wage determination can be found in Groshen (1991a), Krueger and Summers (1988) and Nolan and Brown (1983). These are drawn upon in this section, which emphasises between-establishment wage dispersion.

2.1. Theoretical Models

Sorting theory suggests, assuming worker ability heterogeneity, different employers hire workers with similar abilities (productivities). There are two relevant strands of literature. First, job matching assumes employers and workers face limited information (Jovanovic, 1979). The worker-job match has a known productivity distribution, a particular draw from which is only revealed with increasing tenure. The employer productivity distribution motivates sorting. Second, within an establishment, low productivity workers may impose a negative externality on more productive colleagues (Akerlof, 1981). Related arguments can be found in the team productivity literature.

Empirically, Krueger and Summers (1988) find sorting according to observables unimportant determinants of between industry differentials. However, employer sorting according to unobservables cannot be ruled out and motivates employer agency in firm pay policy.

Theories of asymmetric information assume asymmetric information in job search (Rothschild and Stiglitz, 1976). This can motivate between employer variance if employers face a differential search cost among the worker reservation wage distribution.

Compensating differentials may occur when the observed wage does not fully reflect working conditions. Employer differentials can be associated with common fringe benefits or unemployment hazards (Freeman, 1981). However, most of the literature focuses on occupation rather than employer differentials (Rosen, 1985). Empirically, these effects have only been found important in association with occupational physical risk.

Efficiency wage theories show that wage premia may increase worker productivity and maximize employer profit (Yellen, 1984). With costly monitoring, higher wages decrease the incentive for workers to shirk and consequently increase productivity (Lazear, 1979; Shapiro and Stiglitz, 1984). Alternatively, turnover and vacancy costs may be reduced by higher wages making outside alternatives relatively less attractive (Lang, 1991). Workers paid equilibrium wages will queue, and incumbents will avoid job loss.

Theories of rent sharing suggest that wage contracts reflect the size of the rent and worker bargaining power relative to employers (Lindbeck and Snower, 1987). Blanchflower, Oswald and Garrett (1990) find support for this with UK data.

2.2. Empirical Evidence

Wage variation between industries has received much attention in the literature. The importance of industry differentials is supportive of employer effects since there exists heterogeneity even among narrowly classified industries according to product markets. Dickens and Katz (1987) attribute 7-30% of individual wage variance to industry effects. Within industry (between employer) differentials are thinner on the ground. Nolan and Brown (1983) find employer effects important determinants of UK wage variance. Groshen (1991a) finds employers accounting for 10-15% of wage variance within industry-occupation. Employer size (Brown and Medoff, 1989), gender composition (Blau, 1977), occupation (Ward, 1980), location and industry (Groshen, 1991b) are important explanatories of the employer-wage effect.

A small number of US studies match certain employer and worker data in a cross section to identify establishment wage differentials. Davis and Haltiwanger (1991) use a large sample of US manufacturing plants observed each 5 years 1963-82 and match with individuals from the Census. It is found that plant heterogeneity accounts for 50% and observables 50% of the log wage variance. Bronars and Famulari (1996) use pilot survey data for US establishment on white collar workers. Establishment heterogeneity is found to account for 18% and worker observables 57% of log wage variance. Lacking a panel element and hence control for individual heterogeneity, these studies are appropriate for comparison with Danish workplace-only decompositions.

Abowd Kramarz and Margolis (1994) (henceforth AKM) are the first to statistically analyse together worker and enterprise heterogeneity in earnings. A very large sample (4%) of French private sector enterprise and workers are followed 1978-88. The econometric framework is a projection method attributed to Chamberlain (1984) and Mundalk (1978). This is effectively a mixed random effect and fixed effect approach estimated by GLS. Both individual and firm heterogeneity are found to be important, though individual effects are three times larger. Correlated individual and firm effects are found to be quite weak. This study provides the best bench-mark against which to judge our results, and gives a strong motivation for our more parsimonious modelling approach.

3. Data

Data are from the Integrated Database for Labour Market Research (IDA) created by Statistics Denmark. IDA contains information on labour market conditions for the population of individuals and establishments in Denmark over the years 1980-1991. The information originates in various administrative registers and is merged by Statistics Denmark.

The novel feature of IDA is that it is possible to associate workplaces with the identity of all employees at a specific time of the year. Information on these individuals can then be retrieved from the administrative registers and merged. In that way it is possible to get a picture of the characteristics of the entire workforce of all workplaces. Demographic information on individuals is in common with most labour panels, and much of the workplace information we are able to use consists of aggregates thereof. Confidentiality concerns deny access to all economic data on firms such as profit, turnover, and productivity. For a more detailed description of IDA, see Leth-Sørensen (1995).

Two other studies have previously used IDA samples. Albæk and Sørensen (1995) examine worker turnover for the population of manufacturing workplaces. Bingley and Lanot (1996) look at retirement using a 5% sample of elderly males.

3.1. Sample

For this study, a 5% sample of private sector workplaces has been constructed. A workplace is defined as a legally-registered unit with a unique physical address. A number of workplaces belong to multi-plant firms, but for 70% of workplaces there is a one to one relation. The sampling frame is workplaces with 5-500 primary employees in 1980. Primary employees are workers with main source of labour market earnings due to this workplace attachment. These workplaces are followed until 1991 with replacement representative of workplace birth. All primary workers are matched each year. Attachment is on the basis of November employment with the workplace in question.

We drop the first observation of each workplace in order to get a measure of employee turnover and workplace growth and to create a tenure indicator for a newcomer to the workplace. This amounts dropping 12.0% plants, 12.8% workers, 12.6% observations. Hence we have no direct observations for 1980. The criteria for an observation being in the worker matched sample is that we observe a positive wage (7.2% zeros), that the wage is not top-coded (less than 0.1% at 1991 DKr 500 per hour), all explanatory variables are valid (4.7% dropped).

Dimensions of the estimation panel sub-sample are presented graphically in a data appendix. Here we give a brief discursive summary.

The size of the workplace sample reflects the aggregate business cycle during the investigated period with decreasing total employment to 1982, increasing 1983-86, and stagnation 1988-91. Number of employees develops similarly as is to be expected. We observe most plants throughout all 11 years, and a much smaller number for shorter periods. The number of years we observe each worker has a mean of 3.03. A number of workers spend only a very short time in a sampled plant, with high rates of turnover particularly concentrated among the young.

Most workers are observed only in one sampled workplace However, because of the size of our sample relative to the population and high worker mobility, we are able to observe some (4.2%) who move among different sampled plants. This information is used to identify a workplace effect from a workplace-worker "match" effect (see below).

Median number of workers per plant has increased very slightly over time. This may be a feature of the replacement sampling frame being representative of births rather than of the whole population. Mean workplace size is 24 primary workers. This compares with 11 and 13 workplace and firm means for the population respectively. Danish enterprises are small relative to the US, but typical of Europe. Mean size of firms with 10 or more employees in the US is 83 and EU is 62. Figures for all EU firms are for example: Germany 9, France 7, UK 3, Sweden 12 (Eurostat 1992). However, the number of pooled observations of workers for each workplace (mean 114) is rather large, and suggests we will be able to identify workplace effects well in estimation.

3.2. Descriptives

Information at the worker level comprises: education, experience, earnings, hours, occupation, marital status, children. At the workplace level: ownership, number of workplaces in firm, size, employee turnover, region, industry, *but no economic data*. Here we describe each of the variables in detail and relegate exhaustive groupwise descriptives to a data appendix.

Individual information has much in common with other labour market panels. *Education* is conventional total years of full-time education. *Experience* measures the years of actual labour market experience recorded by the mandatory labour market pension (ATP) administration. ATP contributions are recorded from 1964, and the group (30.4%) who were potentially working before that date are added their potential experience according to length of education.

Workplace or enterprise tenure or seniority is not recorded directly. We are able compute tenure within the dataset, but to avoid ad hoc coding in estimation which would address this censoring problem we choose to only identify *newcomers* to the workplace. Altonji and Shakotko (1987) demonstrate the return to tenure is by far the highest in the first year.

Earnings data comes from tax records incorporating all labour market income according to each employer each fiscal year (January-December). Hours worked are derived from ATP contributions which are made weekly according to four hour bands. Hourly *Wages* are calculated from these and top coded at (1991) DKr 500 per hour.

Apprentice identifies workers undergoing on-the-job training as part of the extensive Danish apprenticeship system. Other (single digit) *occupation* information is omitted from the analysis on the grounds that it is highly correlated with education.

At the workplace level we have a couple of specific variables. *# plants* indicates multi-workplace firms. The small number of multiples supports comparisons between the present work and enterprise level studies. *Ownership* distinguishes shareholder from privately owned firms and a remainder which comprises foundations, co-operatives and other legal entities. Additionally workplaces may be classified according to broad groupings. *Industry* is a single digit SIC classification (aggregated from 3 digits). *Region* indicates one of eight geographical locations for the workplace. A similar variable is available for workers home address, but not used in the analysis because of the limited additional information given the broad classification. *Regional Unemployment* rate is an annual percentage figure matched by *Region*.

Furthermore, our exhaustive within-workplace sampling frame enables us to compute several workplace-level employee aggregates. *Size* indicates the number of primary workers attached in November. *Turnover* is a gross measure of primary employment change, computed from the difference in *Size* between this year and last all divided by mean *Size* in the two years. *Secondary Worker Ratio* is the ratio of secondary to all November employees. Similarly *Female Ratio, Manual Ratio* and *Apprentice Ratio* are workplace proportions of those groups.

4. Econometric Framework

Our econometric model is motivated by the novel grouped nature of the IDA data. We can group observation according to the workplace, worker, year. Moreover, the workplace-level sampling frame and the administrative nature of the dataset allows us to follow all workers while they remain at a workplace during 1980-91. Large sample size relative to the population allows identification of cross-overs or cross-level effects, despite the sampling frame.

Explicitly modelling grouping has several advantages which all spring from the empirical regularity that observations which may be considered "clustered" in some meaningful way are more alike than observations chosen from the population at random. More formally stated, subject to certain assumptions we can, efficiently estimate regression coefficients, provide asymptotically valid standard errors, explore between-worker and between-workplace differences in wages according to characteristics of workplaces and workers which are both observed and unobserved.

In the present context, the variable of interest, log real hourly earnings y, has three subscripts. The first distinguishes the workplace i, the second distinguishes the worker j, the third distinguishes the time period t. We observe N workplaces, J workers and T time periods. Assume responses y_{ijt} depend linearly on unknown coefficient vector β.

$$y_{ijt} = x'_{ijt}\beta + \varepsilon_{ijt}$$

where x_{ijt} is a design vector of explanatory variables, β is an associated vector of coefficients and ε_{ijt} is a random disturbance term. This disturbance may be decomposed

$$\varepsilon_{ijt} = \eta_i + \mu_j + \theta_t + \kappa_{ij} + \psi_{it} + \omega_{jt} + \nu_{ijt}$$

Our data set-up suggests two identification restrictions must be imposed on the error structure. First as is common in labour panels, a small number of observations per worker ($T_i =< 11, \overline{T} = 3$) means a pure time variance will be hard to fit and it is better modelled with year dummies. Second, we only observe primary wages (and have no wages for other employments), so each worker during each time period can only be observed in one plant. Consequently we cannot distinguish ω_{jt} from ν_{ijt}. Henceforth this combined error component shall be denoted $\nu_{(i)jt}$.

$$\varepsilon_{ijt} = \eta_i + \mu_j + \kappa_{ij} + \psi_{it} + \nu_{(i)jt}$$

Derivation of an appropriate Weighted Least Squares estimator is relegated to a technical appendix. The appendix derivation is for the (general) fully identified case, of which ours is a special case. The presentation is in the context of a fully balanced panel for the purposes of exposition. However, our panel is unbalanced at the plant, worker and match level. Appropriate weights are used (simply book-keeping). The maintained assumption is that attrition (of workplaces and workers) from the panel is random and therefore ignorable.

In the text that follows we shall loosely follow the convention of the statistics literature (Goldstein, 1995), by referring to the above as a "3-level" model (3 indices), and to the familiar simple error components set-up as a "2-level" model (2 indices). Our model is not strictly 3-level since we allow for cross-overs between groups, and is in this sense more general.

It is necessary to put this model in the context of important issues which have not been addressed. We assume worker mobility is random and ignorable in wage determination. Something which all the theory discussed suggests is not the case as its primary motivation. The extent to which mobility (and hence exclusion from the sample) is correlated with wages can cause bias in estimates. Keane, Moffitt and Runkle (1989) address this problem in the 2-level case. However, in a multi-level context this is a serious undertaking beyond the scope of the present study. Even

ignoring attrition, more involved dynamics of individual wages have long been found important, such as autocorrelation and growth curves (Lillard and Willis, 1978). Both are tractable extensions in this context[2] and there is scope for future work.

5. Results

Table 1 *One and Three Level Estimators*
Selected model estimates (standard errors)

Level		Estimator	
	Variable	OLS	Random Effect
	Intercept	4.24330 (.01505)	4.22230 (.01370)
	Male	.00401 (.00796)	-.01241 (.00911)
Worker Human Capital			
	Female × education	.02379 (.00050)	.02255 (.00059)
	Female × experience	.01685 (.00048)	.01632 (.00050)
	Female × experience^2	-.00034 (.00001)	-.00030 (.00001)
	Female × newcomer	-.02079 (.00265)	-.01289 (.00210)
	Female × married	.01214 (.00225)	.01504 (.00233)
	Male × education	.03449 (.00037)	.03490 (.00044)
	Male × experience	.02053 (.00026)	.02080 (.00028)
	Male × experience^2	-.00038 (.00000)	-.00037 (.00000)
	Male × newcomer	-.03475 (.00204)	-.01519 (.00163)
	Male × married	.07505 (.00188)	.05839 (.00194)
	Apprentice	-.33497 (.00426)	-.30270 (.00392)
Workplace Characteristics			
	Apprentice ratio	-.10542 (.01292)	-.01561 (.01172)
	Male ratio	.06178 (.00346)	.05900 (.00417)
	Manual ratio	.00405 (.00341)	-.00307 (.00401)
	Secondary ratio	-.04210 (.01178)	.00227 (.01100)
	Turnover	.04127 (.00516)	.02885 (.00469)
	Size	.00001 (.00000)	.00004 (.00000)
	# Plants = 1	-.02224 (.00167)	-.01521 (.00188)
	# Plants ≥ 9	-.06057 (.00214)	-.04206 (.00249)
	Ownership personal	-.06550 (.00263)	-.04699 (.00301)
	Ownership co-op, foundation	-.01881 (.00151)	-.01392 (.00171)
	Regional unemployment	.11827 (.13097)	.28648 (.10578)
Observations		202536	202536
R^2		0.3543	0.9020

Conventional OLS, 2-level fixed and random effects for each grouping and 3-level random effect models have all been estimated. Table 1 presents headline coefficients of interest.

2. Incorporating autocorrelation in a hierarchical model at the lowest (worker) level involves a further transformation and similar spectral decomposition. Hierachical mixed models allowing for workplace specific returns to human capital would offer a substantive interpretation of employer differentials

Additional controls for 2-digit industry, region and year are relegated to an appendix. These OLS coefficients are discussed in the next sub-section, followed by a contrast with GLS. We proceed with diagnostic checks and conclude with a description of the implied error components.

5.1. Single Level (OLS) Estimates

Estimates for the pooled observations, ignoring worker and plant groupings, are highly significant as should be expected with such a large sample size and parsimonious specification. Gender is interacted with human capital variables to allow differential returns. Consequently of worker-specific characteristics, *male* is the only insignificant coefficient. Returns to *education* and *experience* are relatively low at 3% and 2% respectively for males and slightly less for females. This is in accordance with other results for the Nordic countries (Asplund et al, 1996).

The tenure proxy, *newcomer*, should be interpreted as the mean penalty to one year of tenure relative to the mean of all longer tenures. Mean on-going establishment tenure for the private sector is about seven years. These large penalties are in line with the highly non-linear seniority returns found in US work (Altonji and Shakotko, 1987). *Apprentices*, most of whom are male, receive a third lower wages in accordance with union agreements. Being *married* is worth 1% for females and 8% for males.

Workplace aggregates are much less common in the literature and as such more interesting than the worker human capital returns. Once again we have a lot of significance, with the exception of *manual worker ratio* and *regional unemployment*. Workplaces with a high proportion of apprentices and secondary workers pay all of their primary workers less. *Male workplaces* pay more, which mainly affects the individually insignificant male dummy. Employer *size* effects are conventionally positive and significant. *Shareholder firms* and those with a moderate *number of workplaces* (2-8) pay best.

5.2. Multi-Level (GLS) Estimates

The error components model controls for unobserved heterogeneity of workers, workplaces and matches, which might otherwise bias OLS estimates through spurious association, and gives standard errors from which to make valid inference.

At the worker level, returns to human capital remain unchanged. The male marriage premium falls when we control for worker unobservables, as we should expect the direct effect of marriage

on productivity to be marginal. The penalty to being a *newcomer* halves to 1% once we allow for match heterogeneity. This seniority proxy is the only match-specific observable and in OLS spuriously attributes match unobservables, biasing the returns to tenure upwards.

Accounting for workplace heterogeneity has a much greater impact on the coefficients of the aggregates. The only *ratio* remaining significant is *male*. The wage premium to a high turnover workplace falls but remains strongly significant. *Size* effects increase in line with previous results which found these robust to workplace *or* worker panels.

Differentials according to workplace *ownership* and *multi-plants* fall but remain significant. Surprisingly *regional unemployment* becomes positive, in contrast to the wage curve hypothesis advanced by Blanchflower and Oswald (1995). Though this is not very significant and we have controlled for its two dimensions of variation, *region* and *year* (see appendix).

These results can be collected in partial evaluation of various theories of wage determination. The turnover version of efficiency wage theory whereby turnover (with associated re-training and unfilled vacancy) costs are reduced through higher wages is not supported by the positive turnover coefficient. However, a monitoring cost version is supported by higher wages for large shareholder firms with a moderate number of plants. Rent sharing is not supported by the data in our full model. This is evidenced by proxies for intra-workplace divisions such as ratios of apprentices, manual and secondary workers which disappear once unobserved heterogeneity is controlled for, particularly at the workplace level. Compensating differentials for unemployment hazard are indicated with a positive turnover coefficient.

5.3. Diagnostics

While we perform no formal tests of our specification and econometric framework, we discuss the differences between the various estimators we have applied, examine the correlation of the estimated group effects with explanatories, and place our estimates in the applied panel literature.

Comparing fixed and random effects estimates for the various groupings, the similarities are striking (see tables 5 and 6 in the appendix). Where they most differ is according to worker grouping. The within estimator (with 64,000 more coefficients) suggests that there is a moderate bias in the random effects coefficients. In particular the return to human capital appears to be downward biased.

To motivate a random effects approach we must justify the assumption of full orthogonality. So the off-diagonals of the correlation matrix between the explanatory variables and the group-specific effects should be zeros[3]. Table 2 presents the correlation matrix for our sample and compares with that AKM found for French data. Their study also provides the only current bench-mark decomposition of the effects of individual and firm heterogeneity on wages.

Table 2 Estimated Correlation Matrices

Danish Establishments

	$X\hat{\beta}$	η_i	μ_j
$X\hat{\beta}$	1.0000	0.0666	0.0241
η_i	0.0666	1.0000	0.0308
μ_j	0.0241	0.0308	1.0000

French Enterprises

	$X\hat{\beta}$	η_i	μ_j
$X\hat{\beta}$	1.0000	0.0710	0.0325
η_i	0.0710	1.0000	0.0974
μ_j	0.0325	0.0974	1.0000

Ignoring workplace identifiers, and estimating a simple worker-effect model (with a correlation of 0.067) is where our orthogonality assumption is most in question. However, it is conventional to estimate such individual random effects models of wage determination in the literature, and if one is willing to buy this orthogonality assumption, the further assumptions necessary to motivate our model are much less strong.

A weak correlation of individual and firm effects justifies our assumption of independent effects. AKM also find that pure heterogeneity due to standard worker random effects is more important than firm specific intercept and tenure slopes. This further supports an error component framework. It is pertinent to note that we find less sorting of for example able workers to productive workplaces as evidenced by the low correlation (0.031) of specific effects.

5.4. Variance Decomposition

The empirical mean and total variance of log real wages are 4.80 and 0.12 DKK/hour respectively. Our data allows us to group observations according to worker, workplace and match (unique combination of worker and workplace). Total raw variance can be decomposed within these groups respectively 14.6, 74.2 and 13.7%. This raw variance can be attributed to observables and unobservables due to each of the various groupings using a multi-level approach.

3. Group-specific effects are computed from separate within-worker and within-workplace estimations (see appendix table 5).

Decompositions for the 2-level models are estimated separately for each grouping and are shown in the upper part of table 3. These decompositions are computed as follows. Explained variance is the traditional total R^2 measure. Unobserved heterogeneity is the proportion of the variance attributable to the particular grouping being considered. Within groups this is the empirical variance of the estimated fixed effects. For Random effects models it is estimated directly. As is usually the case, the latter are estimated to be smaller than the former. Total variance attributed is the sum of variance due to observables and variance due to the grouping in question.

Table 3 *2-Level and 3-Level Models*
Error Components Summary

Estimator	% Variance	Worker	Match	Workplace
2-Level				
Fixed Effect	Explained	12.8	12.2	31.8
	Unobs. Heterogeneity	73.4	74.9	26.2
	Total Attributed	86.2	87.1	58.0
Random Effect	Explained	26.4	26.5	32.2
	Unobs. Heterogeneity	53.8	54.4	22.0
	Total Attributed	80.2	80.9	54.2
3-Level				
Random Effect	Explained*	-	20.4	-
	Unobs. Heterogeneity	38.0	5.8	26.2
	Total Attributed*	-	90.4	-

*Percentage of variance explained and attributed after accounting for all three groupings *simultaneously*.

The three-level model shown in the lower panel of table 3 is estimated jointly for all groupings and should be interpreted slightly differently bearing in mind that each source of heterogeneity is estimated consistently. The headline result is that the variance can be decomposed into 20.4, 38.0, 5.8, 26.2, 9.6% respectively to observables, unobserved heterogeneity of workers, matches and workplaces, and that which remains unattributed. An estimated ψ_{it} (workplace-time) variance of zero indicates firm pay policy is able to respond to prevailing labour market conditions. This is not supportive of theories of internal labour markets.

It is interesting to compare estimators which account for different levels. For the worker grouping, percentage of variance "explained" i.e. attributed to observables and worker heterogeneity is 86.2, 80.2 and 58.4 for 2-level fixed effects, 2-level random effects and 3-level random effects respectively. So, parameterising the heterogeneity with a random effect at two levels only reduces the attributable variance by 6.0%. Further assuming full orthogonality of all the

groupwise error terms reduces worker heterogeneity by 21.8% to a "clean" 58.4%, i.e. we have controlled for the workplace and match heterogeneity that would otherwise be attributed to workers.

Similarly for the workplace grouping, percentage of variance "explained" i.e. attributed to observables and workplace heterogeneity is 58.0, 54.2 and 26.2 for 2-level fixed effects, 2-level random effects and 3-level random effects respectively. So, parameterising the heterogeneity with a random effect at two levels only reduces the attributable variance by 3.8%. Further assuming full orthogonality of all the groupwise error terms reduces worker heterogeneity by 28.0% to a "clean" 26.2%, i.e. we have controlled for the worker and match heterogeneity that would otherwise be attributed to workplaces.

In total, the proportion of the variance we are now able to attribute to our three sources of unobserved heterogeneity is (38.0 + 5.8 + 26.2) 70.0%. Previous estimates of worker heterogeneity are biased upwards because they fail to account for workplace and match groupings. Estimated workplace-level unexplained variance is robust to choice of estimator. This is surprising to the extent that pure workplace effects may be thought to be upward bias due to worker sorting.

Match heterogeneity is found to be much less important than worker and workplace effects. However, matching models are supported by our error components decomposition. Match heterogeneity *per se* is quite small at 6%, but scope for search by workers is large (26% workplace unobserved heterogeneity) and by firms is even larger (38% worker unobserved heterogeneity).

Once again we are able to put these results into perspective by considering AKM which provides the only other comparable approach. Using only an enterprise (not workplace) grouping and worker explanatories, 57% of the variance is accounted for. Our comparable figure is (32 + 22) 54%. In a model coherently accounting for enterprise and worker (not match) heterogeneity they are able to explain 80% of the variance, attributing 25% to enterprise unobservables. Our comparable figures are (20 + 38 + 6 + 26) 90 and 26% for establishments respectively.

6. Conclusions

We have found strong evidence of firm-specific pay policy in the form of establishment wage differentials after having controlled for worker and match effects. There is scope for search on both sides of the labour market. There is support for monitoring cost versions of efficient labour contracts, from the coefficients on size, number of workplaces and type of ownership. Com-

pensating differentials are evidenced through a positive coefficient on workplace turnover. However we do not find support for models of rent sharing through insignificant worker group ratios. Furthermore internal labour markets are not supported through the degenerate variance of workplace-time effects.

It is important to put these results in the context of our maintained assumptions. Mobility and attrition from the sample are ignorable and we have full orthogonality between explanatories and all estimated error components. These caveats aside, what is missing in order to test more directly competing theories of wage determination is economic information at the firm level. The present study provides some simple and new results. The hope is that it also provides a basis on which to proceed in the analysis of a growing number of matched employer-worker panels, which offer enormous potential for future research.

7. References

Abowd, John, Francis Kramarz and David Margolis (1994) *High-Wage Workers and High-Wage Firms*, **NBER Working Paper, 4719**.

Abowd, John, Francis Kramarz and David Margolis (1996) *The Entry and Exit of Workers and the Growth of Employment: An Analysis of French Establishments*, **NBER Working Paper, 5551**.

Akerlof, George (1981) *Jobs as Dam Sites*, **Review of Economic Studies, 48**, 37-49.

Asplund, Rita, Erling Barth, Carl le Grand, Arne Mastekaasa and Niels Westergård-Nielsen in E. Wadensjö **The Nordic Labour Market in the 1990's,** North -Holland, Amsterdam, (1996)

Albæk, Karsten and Bent Sørensen (1995) *Worker Flows and Job Flows in Danish Manufacturing, 1980-91*, **Mimeo**.

Altonji, Joe and Robert Shakotko, (1987) *Do Wages Rise with Job Seniority?*, **Review of Economic Studies, 54**, 437-459.

Baltagi, Badi (1993) *Useful Matrix Transformations for Panel Data Analysis: A Survey*, **Statistical Papers, 34**, 281-301.

Bingley, Paul and Gauthier Lanot (1996) *Danish Private Sector Wage Policies and Male Retirement Decisions*, **CLS Working Paper, forthcoming.**

Blanchflower, David, Andrew Oswald (1995) *An Introduction to the Wage Curve*, **Journal of Economic Perspectives, 9**, 153-167.

Blanchflower, David, Andrew Oswald and Mario Garrett (1990) *Insider Power in Wage Determination*, **Economica, 57**, 143-170.

Blau, Francine (1977) **Equal Pay in the Office**, Lexington: D.C. Heath.

Bronars, Steven and Melissa Famulari (1996) *Wage, Tenure, and Wage Growth Variation Within and Across Establishments*, **Journal of Labor Economics, forthcoming**.

Brown, Charles and James Medoff (1989) *The Employer Size Wage Effect*, **Journal of Political Economy, 97**, 1027-1059.

Calmfors, Lars and John Driffill (1988) *Centralisation of Wage Bargaining and Economic Performance,* **Economic Policy, 10**, 13-61.

Chamberlain, Gary (1984) *Panel Data,* in Z. Grilliches and M. D. Intrilligator (eds.), **Handbook of Econometrics, Volume 2**, 1247-1318.

Davis, Steven and John Haltiwanger (1991) *Wage Dispersion Within and Between US Manufacturing Plants 1963-86*, **Brookings Papers on Economic Activity, Microeconomics**, 115-180.

Davis, Steven and John Haltiwanger (1992) *Gross Job Creation, Gross Job Destruction and Employment Reallocation*, **Quarterly Journal of Economics, 107**, 819-863.

Dickens, William and Lawrence Katz (1987) *Inter-Industry Wage Differentials and Theories of Wage Determination*, **NBER Working Paper, 2271**.

Eurostat (1992) **Enterprises in Europe**, Brussels: Commission of the European Communities.

Freeman, Richard (1981) *The Effect of Unionism on Fringe Benefits*, **Industrial and Labour Relations Review, 34**, 489-509.

Fuller, Wayne and George Battese (1973) *Transformations for Estimation of Linear Models with Nested Error Structure,* **Journal of the American Statistical Association, 68**, 626-632.

Goldstein, Harvey (1995), **Multi-level Statistical Models**, New York: Wiley.

Groshen, Erica (1991a) *Source of Intra-Industry Wage Variation: How Much Do Employers Matter?*, **Quarterly Journal of Economics, 106**, 869-884.

Groshen, Erica (1991b) *Five Reasons Why Wages Vary Among Employers*, **Industrial Relations, 30**, 350-381.

Jackman, Richard (1989) *Wage Formation in the Nordic Countries Viewed from an International Perspective*, **London School of Economics Discussion Paper, 335**.

Jovanovic, Boyan (1979) *Job Matching and the Theory of Turnover*, **Journal of Political Economy, 87**, 972-990.

Keane, Michael, Robert Moffitt and David Runkle (1988) *Real Wages over the Business Cycle: Estimating the Impact of Heterogeneity with Micro Data*, **Journal of Political Economy, 96**, 1232-1265.

Krueger, Alan and Larwence Summers (1988) *Efficiency Wages and Inter-Industry Wage Structure*, **Econometrica, 56**, 259-293.

Lang, Kevin (1991) *Persistent Wage Dispersion and Involuntary Unemployment*, **Quarterly Journal of Economics, 106**. 181-202.

Lazear, Edward (1979) *Why is there Mandatory Retirement?*, **Journal of Political Economy, 87**, 1261-1284.

Leth-Sørensen, Søren (1995) *The IDA Database: A Longitudinal Database of Establishments and their Employees*, **Statistics Denmark Working Paper, 95:5**.

Lillard, Lee and Robert Willis (1978) *Dynamic Aspects of Earnings Mobility*, **Econometrica, 46**, 985-1012.

Lindbeck, Assar (1993) **Unemployment and Macroeconomics**, Cambridge: MIT Press.

Lindbeck, Assar and Dennis Snower (1987) *Efficiency Wages Versus Insiders and Outsiders*, **European Economic Review, 31**, 407-416.

Mundalk, Y. (1978) *On the Pooling of Time Series and Cross Section Data*, **Econometrica, 46**, 69-85.

Nolan, Peter and William Brown (1983) *Competition and Work Place Wage Determination*, **Oxford Bulletin of Economics and Statistics, 45**, 269-287.

OECD (1994) **The OECD Jobs Study: Evidence and Explanations**, Paris: OECD.

Rosen, Sherwin (1986) *The Theory of Equalizing Differences*, in Orley Ashenfelter and Richard Layard (eds.) **Handbook of Labor Economics, Volume 1**, Amsterdam: North Holland.

Rothschild, Michael and Joseph Stiglitz (1976) *Equilibrium in Competitive Insurance Markets: An Essay on the Economic of Imperfect Information*, **Quarterly Journal of Economics, 90**, 629-649.

Rowthorn, Richard (1992) *Centralisation, Employment and Wage Dispersion*, **Economic Journal, 102**, 506-523.

Shapiro, Carl and Joseph Stiglitz (1984) *Equilibrium Unemployment as A Worker Discipline Device*, **American Economic Review, 74**, 433-444.

Wansbeek, Tom and Arie Kapteyn (1982) *A Class of Decompositions of the Variance-Covariance Matrix of a Generalized Error Components Model*, **Econometrica, 50**, 713-724.

Wansbeek and Kapteyn (1983) *A Note on Spectral Decomposition and Maximum Likelihood Estimation*, **Statistics and Probability Letters, 1**, 213-215.

Ward, Virginia (1980) *Measuring Wage Relationships Among Selected Professions*, **Monthly Labor Review, 103**, 21-25.

Yellen, Janet (1984) *Efficiency Wage Models of Unemployment*, **American Economic Review, 74**, 200-205.

8. Appendices

8.1. Descriptive Statistics

Table 4a *Groupwise Descriptive Statistics*
Means of group means

Variable	Cluster						
	pwt	pw	pt	wt	p	w	t
Log Real Wage	4.803	4.753	4.749	4.803	4.741	4.749	4.800
Male	0.623	0.616	0.583	0.623	0.573	0.613	0.624
Female × experience	4.091	3.184	4.480	4.091	4.186	3.185	4.079
Female × experience^2	65.493	46.071	71.411	65.493	64.324	46.031	65.174
Female × education	4.154	4.222	4.599	4.154	4.675	4.256	4.142
Female × newcomer	0.093	0.191	0.105	0.093	0.138	0.193	0.093
Female × married	0.214	0.175	0.246	0.214	0.231	0.176	0.215
Male × experience	10.911	8.675	9.825	10.911	9.112	8.547	10.939
Male × experience^2	287.106	213.994	254.895	287.106	230.973	210.458	288.255
Male × education	7.076	6.951	6.636	7.076	6.502	6.910	7.076
Male × newcomer	0.149	0.301	0.141	0.149	0.171	0.300	0.149
Male × married	0.365	0.297	0.328	0.365	0.309	0.294	0.367
Apprentice	0.027	0.047	0.034	0.027	0.041	0.048	0.027
Apprentice ratio	0.027	0.031	0.034	0.027	0.041	0.031	0.027
Male ratio	0.623	0.616	0.583	0.623	0.573	0.614	0.624
Manual ratio	0.417	0.430	0.384	0.417	0.383	0.429	0.418
Secondary ratio	0.049	0.054	0.061	0.049	0.065	0.054	0.049
Turnover	0.229	0.272	0.247	0.229	0.294	0.270	0.228
Size	93.263	96.798	23.997	93.263	24.215	96.321	92.578
# Places = 1	0.616	0.611	0.709	0.616	0.707	0.618	0.619
# Places ≥ 9	0.165	0.165	0.148	0.165	0.135	0.164	0.164
Ownership private	0.079	0.096	0.208	0.079	0.229	0.097	0.080
Ownership co-op, etc.	0.394	0.388	0.433	0.394	0.409	0.392	0.395
Unemployment	0.092	0.092	0.093	0.092	0.094	0.092	0.092
Construction	0.075	0.085	0.108	0.075	0.102	0.086	0.076
Trade	0.303	0.324	0.346	0.303	0.379	0.326	0.302
Transport	0.072	0.075	0.054	0.072	0.057	0.074	0.071
Finance	0.149	0.129	0.132	0.149	0.122	0.126	0.148
Services	0.127	0.125	0.141	0.127	0.124	0.128	0.128
Copenhagen	0.320	0.352	0.262	0.320	0.270	0.351	0.320
Fred'berg	0.095	0.089	0.096	0.095	0.093	0.089	0.095
W. Sjyland	0.091	0.090	0.090	0.091	0.092	0.087	0.092
S. Jylland	0.082	0.075	0.085	0.082	0.078	0.075	0.082
E. Jylland	0.160	0.162	0.181	0.160	0.178	0.165	0.159
W. Jylland	0.096	0.087	0.108	0.096	0.106	0.088	0.096
N. Jylland	0.063	0.064	0.095	0.063	0.094	0.064	0.063
1981	0.080	0.099	0.089	0.080	0.122	0.099	0.091
1982	0.082	0.079	0.088	0.082	0.087	0.079	0.091
1983	0.081	0.070	0.088	0.081	0.074	0.070	0.091
1984	0.088	0.079	0.089	0.088	0.078	0.079	0.091
1985	0.091	0.084	0.090	0.091	0.079	0.085	0.091
1987	0.093	0.085	0.093	0.093	0.081	0.086	0.091
1988	0.094	0.086	0.093	0.094	0.084	0.086	0.091
1989	0.098	0.095	0.093	0.098	0.091	0.094	0.091
1990	0.100	0.107	0.094	0.100	0.102	0.105	0.091
1991	0.098	0.127	0.091	0.098	0.116	0.128	0.091
Observations	202536	66787	10429	202536	1460	64093	11

Table 4b *Groupwise Descriptive Statistics*
Standard deviations of group means

Variable	Cluster						
	pwt	pw	pt	wt	p	w	t
Log Real Wage	0.346	0.351	0.229	0.346	0.224	0.350	0.051
Male	0.485	0.486	0.326	0.485	0.316	0.487	0.011
Female × experience	6.983	5.963	4.228	6.983	3.719	5.956	0.222
Female × experience^2	156.084	127.166	87.322	156.084	72.156	127.063	5.589
Female × education	5.488	5.493	3.644	5.488	3.479	5.502	0.185
Female × newcomer	0.291	0.355	0.161	0.291	0.173	0.354	0.009
Female × married	0.410	0.373	0.239	0.410	0.217	0.373	0.009
Male × experience	12.964	11.742	7.238	12.964	6.785	11.681	0.398
Male × experience^2	488.233	437.000	241.444	488.233	219.528	434.760	16.361
Male × education	5.777	5.754	3.659	5.777	3.519	5.751	0.094
Male × newcomer	0.356	0.404	0.168	0.356	0.161	0.401	0.013
Male × married	0.481	0.449	0.250	0.481	0.234	0.446	0.028
Apprentice	0.161	0.199	0.092	0.161	0.094	0.200	0.003
Apprentice ratio	0.053	0.058	0.092	0.053	0.094	0.058	0.003
Male ratio	0.275	0.274	0.326	0.275	0.316	0.275	0.011
Manual ratio	0.301	0.297	0.334	0.301	0.319	0.295	0.023
Secondary ratio	0.056	0.057	0.079	0.056	0.071	0.057	0.001
Turnover	0.135	0.145	0.168	0.135	0.166	0.142	0.015
Size	119.096	124.790	39.908	119.096	39.216	123.654	10.882
# Places = 1	0.486	0.478	0.454	0.486	0.438	0.474	0.047
# Places ≥ 9	0.371	0.366	0.355	0.371	0.333	0.364	0.012
Ownership private	0.270	0.289	0.406	0.270	0.403	0.288	0.017
Ownership co-op, etc.	0.489	0.475	0.496	0.489	0.463	0.473	0.055
Unemployment	0.018	0.017	0.019	0.018	0.017	0.017	0.009
Construction	0.264	0.279	0.311	0.264	0.301	0.280	0.008
Trade	0.460	0.465	0.476	0.460	0.479	0.464	0.023
Transport	0.258	0.262	0.226	0.258	0.229	0.260	0.012
Finance	0.356	0.329	0.339	0.356	0.319	0.325	0.016
Services	0.333	0.329	0.348	0.333	0.326	0.332	0.016
Copenhagen	0.466	0.477	0.440	0.466	0.441	0.476	0.012
Fred'berg	0.293	0.284	0.295	0.293	0.286	0.282	0.006
W. Sjyland	0.288	0.286	0.286	0.288	0.288	0.281	0.006
S. Jylland	0.274	0.263	0.279	0.274	0.268	0.263	0.004
E. Jylland	0.367	0.369	0.385	0.367	0.383	0.371	0.016
W. Jylland	0.295	0.282	0.311	0.295	0.307	0.283	0.004
N. Jylland	0.242	0.245	0.293	0.242	0.291	0.245	0.006
1981	0.272	0.244	0.284	0.272	0.216	0.242	0.302
1982	0.274	0.192	0.283	0.274	0.123	0.191	0.302
1983	0.273	0.176	0.283	0.273	0.092	0.174	0.302
1984	0.283	0.196	0.285	0.283	0.101	0.192	0.302
1985	0.287	0.206	0.287	0.287	0.104	0.203	0.302
1987	0.291	0.204	0.290	0.291	0.098	0.202	0.302
1988	0.292	0.201	0.290	0.292	0.108	0.198	0.302
1989	0.298	0.212	0.291	0.298	0.121	0.205	0.302
1990	0.301	0.226	0.292	0.301	0.141	0.219	0.302
1991	0.298	0.273	0.287	0.298	0.189	0.270	0.302
Observations	202536	66787	10429	202536	1460	64093	11

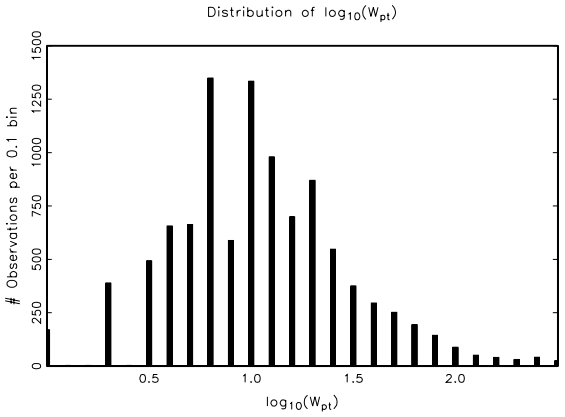
Number of Workers over Time



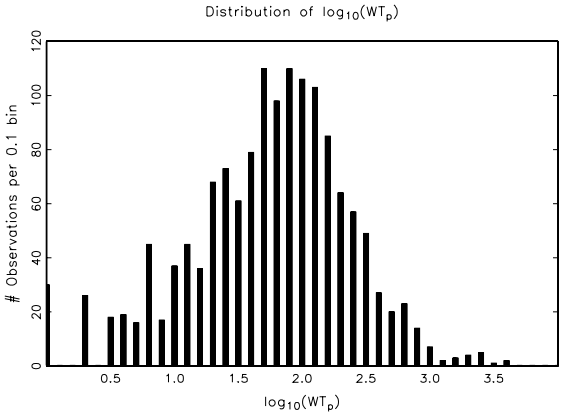
Number of Workplaces over Time



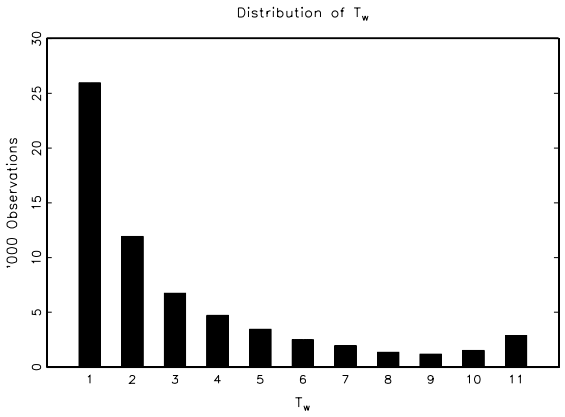
Workplace Size



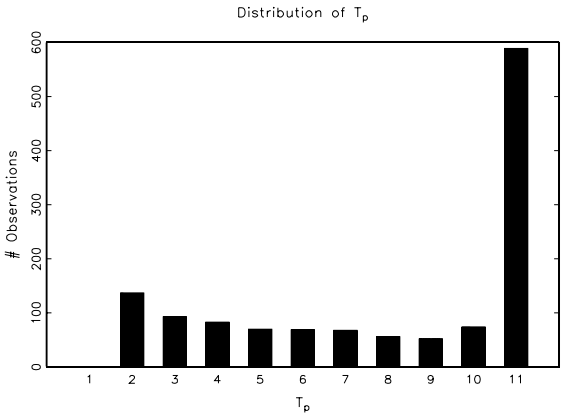
Number of Observations per Workplace



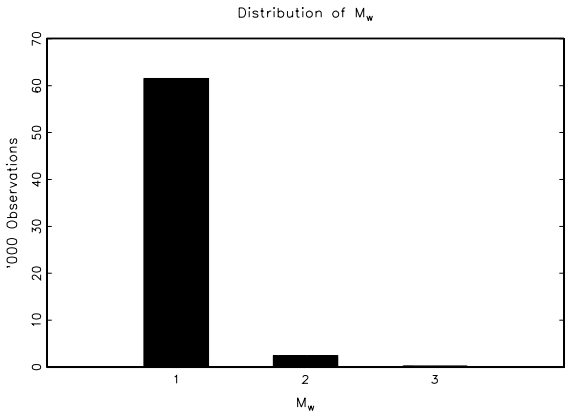
Workers Observation Duration



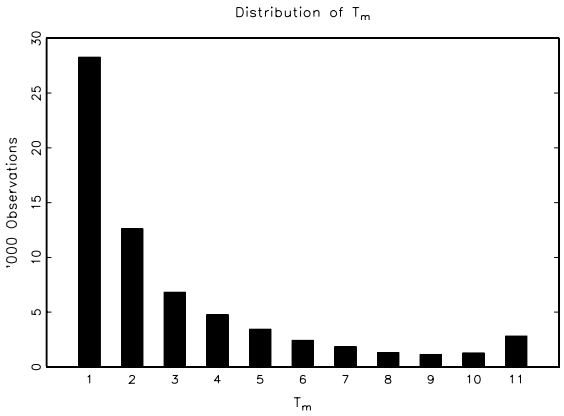
Workplace Observation Duration



Number of Workplaces per Worker



Match Observation Duration



8.2. Auxilliary Estimates

Table 5 2-Level Fixed Effects Model Estimates (standard errors)

Variable	Workplace	Cluster Match	Worker
Intercept	4.3044 (.01347)	4.6172 (.01575)	4.6218 (.01514)
Male	-.00694 (.00746)		
Female × education	.01984 (.00048)		
Female × experience	.01383 (.00044)	.01345 (.00119)	.01295 (.00115)
Female × experience^2	-.00025 (.00001)	-.00023 (.00002)	-.00022 (.00002)
Female × newcomer	-.03067 (.00242)	-.00218 (.00200)	-.00314 (.00199)
Female × married	.01915 (.00208)	.01451 (.00327)	.01401 (.00325)
Male × education	.03112 (.00036)		
Male × experience	.01923 (.00024)	.01528 (.00091)	.01557 (.00088)
Male × experience^2	-.00034 (.00000)	-.00031 (.00000)	-.00032 (.00000)
Male × newcomer	-.03855 (.00186)	-.00307 (.00156)	-.00385 (.00154)
Male × married	.06514 (.00173)	.00627 (.00269)	.00725 (.00267)
Apprentice	-.35050 (.00387)	-.28982 (.00422)	-.29771 (.00418)
Apprentice ratio	.15476 (.01625)	.07998 (.01161)	.07063 (.01156)
Male ratio	-.01662 (.00998)	-.00617 (.00757)	-.00962 (.00715)
Manual ratio	.02394 (.00843)	.00982 (.00631)	.01169 (.00597)
Secondary ratio	.03710 (.01616)	.03583 (.01102)	.02848 (.01094)
Size	.00007 (.00001)	.00014 (.00001)	.00009 (.00001)
Turnover	.07331 (.00672)	.02748 (.00467)	.02940 (.00456)
Unemployment	.04799 (.12518)	.18197 (.09420)	.19772 (.08999)
1981	.01267 (.00317)	-.01431 (.00424)	-.01506 (.00409)
1982	-.00651 (.00350)	-.03883 (.00383)	-.03960 (.00370)
1983	-.02222 (.00414)	-.05335 (.00372)	-.05449 (.00360)
1984	-.01990 (.00381)	-.04711 (.00309)	-.04751 (.00300)
1985	-.00778 (.00301)	-.02228 (.00213)	-.02224 (.00210)
1987	.04014 (.00260)	.04468 (.00178)	.04514 (.00178)
1988	.07246 (.00279)	.07471 (.00230)	.07540 (.00227)
1989	.07670 (.00328)	.07823 (.00308)	.07985 (.00300)
1990	.09726 (.00349)	.10682 (.00373)	.10929 (.00362)
1991	.10736 (.00429)	.12367 (.00468)	.12523 (.00452)
Observations	202506	174254	176583
R^2	0.3180	0.1218	0.1282

Table 6 2-Level Random Effects Model Estimates (standard errors)

Variable	Cluster		
	Workplace	Match	Worker
Intercept	4.2769 (.01301)	4.6013 (.00670)	4.5978 (.00659)
Male	-.00579 (.00745)		
Female × education	.02007 (.00048)		
Female × experience	.01393 (.00044)	.00591 (.00052)	.00597 (.00052)
Female × experience^2	-.00025 (.00001)	-.00000 (.00001)	-.00000 (.00001)
Female × newcomer	-.03058 (.00242)	-.01956 (.00187)	-.01999 (.00186)
Female × married	.01896 (.00207)	.00175 (.00275)	.00114 (.00274)
Male × education	.03122 (.00036)		
Male × experience	.01929 (.00024)	.02539 (.00033)	.02531 (.00032)
Male × experience^2	-.00034 (.00000)	-.00045 (.00000)	-.00045 (.00000)
Male × newcomer	-.03838 (.00186)	.00710 (.00149)	.00585 (.00147)
Male × married	.06538 (.00173)	.03710 (.00229)	.03705 (.00228)
Apprentice	-.34983 (.00387)	-.32263 (.00391)	-.32836 (.00389)
Apprentice ratio	.12849 (.01574)	.01166 (.01098)	.00415 (.01094)
Male ratio	.01122 (.00855)	.07815 (.00495)	.07277 (.00484)
Manual ratio	.01259 (.00749)	-.05542 (.00413)	-.04830 (.00405)
Secondary ratio	.04121 (.01575)	.03876 (.01034)	.02935 (.01028)
Size	.00008 (.00001)	.00010 (.00000)	.00008 (.00000)
Turnover	.06954 (.00657)	.01624 (.00443)	.01848 (.00434)
Unemployment	-.18601 (.11407)	-.58682 (.06476)	-.53634 (.06350)
1981	.01514 (.00310)	.00469 (.00209)	.00416 (.00208)
1982	-.00297 (.00338)	-.01450 (.00216)	-.01526 (.00215)
1983	-.01696 (.00393)	-.02497 (.00241)	-.02631 (.00239)
1984	-.01523 (.00364)	-.02351 (.00223)	-.02441 (.00221)
1985	-.00508 (.00294)	-.00900 (.00181)	-.00941 (.00182)
1987	.04008 (.00260)	.04249 (.00163)	.04273 (.00164)
1988	.07400 (.00276)	.07705 (.00175)	.07700 (.00175)
1989	.08002 (.00318)	.08544 (.00201)	.08561 (.00199)
1990	.10122 (.00336)	.11321 (.00213)	.11407 (.00211)
1991	.11286 (.00406)	.13167 (.00257)	.13155 (.00253)
Observations	202506	174254	176583
R^2	0.3218	0.2645	0.2639

Table 7 *One and Three Level Estimators - continued from main text*
Additional model estimates (standard errors)

Variable	Estimator	
	OLS	Random Effect
Industry		
Construction	.01858 (.00272)	.01444 (.00367)
Trade	-.06577 (.00209)	-.06207 (.00267)
Transport	.00373 (.00279)	-.00022 (.00371)
Finance	.06554 (.00273)	.04626 (.00328)
Services	.02100 (.00273)	.02274 (.00349)
Region		
Copenhagen	.04520 (.00421)	.04621 (.00437)
Fred'berg	.03672 (.00701)	.04639 (.00649)
W. Sjyland	-.03959 (.00296)	-.04112 (.00409)
S. Jylland	-.01526 (.00377)	-.01675 (.00461)
E. Jylland	-.01170 (.00316)	-.01321 (.00394)
W. Jylland	-.02130 (.00489)	-.01636 (.00516)
N. Jylland	-.01288 (.00359)	-.01596 (.00472)
Year		
1981	.01231 (.00332)	.00339 (.00250)
1982	-.00860 (.00369)	-.02026 (.00279)
1983	-.03009 (.00439)	-.03887 (.00336)
1984	-.02641 (.00407)	-.03719 (.00307)
1985	-.00809 (.00327)	-.01687 (.00232)
1987	.03873 (.00286)	.04045 (.00194)
1988	.07522 (.00302)	.07024 (.00214)
1989	.08016 (.00350)	.07188 (.00260)
1990	.10027 (.00371)	.09462 (.00280)
1991	.10899 (.00451)	.10348 (.00352)
Observations	202536	202536
R^2	0.3543	0.9020

8.3. Technical Details: A 3-Level Crossed Error Components Model

The variable of interest, log real hourly income *y*, has three subscripts. The first distinguishes the plant *i*, the second distinguishes the worker *j*, the third distinguishes the time period *t*. We observe *N* plants, *J* workers and *T* time periods. Assume responses y_{ijt} depend linearly on unknown sample-specific effects β and on unknown cluster-specific effects γ_{ijt}

$$y_{ijt} = x'_{ijt}\beta + \varepsilon_{ijt}$$

where x_{ijt} is a design vector of explanatory variables, and ε_{ijt} is a normal disturbance term. This disturbance may be decomposed

$$\varepsilon_{ijt} = \eta_i + \mu_j + \theta_t + \kappa_{ij} + \psi_{it} + \omega_{jt} + \nu_{ijt}$$

Stacking over *t* we obtain column vectors of order $(T \times 1)$

$$\varepsilon_{ij} = \eta_i \iota_T + \mu_j \iota_T + \theta + \kappa_{ij} \iota_T + \psi_i + \omega_j + \nu_{ij}$$

where $\psi_i = (\psi_{i1}, \ldots, \psi_{iT})'$, $\omega_i = (\omega_{i1}, \ldots, \omega_{iT})'$, $\nu_i = (\nu_{i1}, \ldots, \nu_{iT})'$, ι_T is a T column vector of ones. Now, stacking over j we obtain column vectors of order $(TJ \times 1)$

$$\varepsilon_i = \eta_i \iota_J \iota_T + \mu \otimes \iota_T + \theta \otimes \iota_J + \kappa_i \otimes \iota_T + \psi_i \iota_J + \omega + \nu_i$$

where $\mu = (\mu_1, \ldots, \mu_J)'$, $\kappa_{i1} = (\kappa_{i1}, \ldots, \kappa_{iJ})'$, $\omega = (\omega_1, \ldots, \omega_J)'$, $\nu_i = (\nu_{i1}, \ldots, \nu_{iJ})'$, ι_J is a J column vector of ones. Now, stacking over i we obtain column vectors of order $(TJN \times 1)$

$$\varepsilon = \eta \iota_J \iota_T + \iota_N \otimes \mu \otimes \iota_T + \theta \otimes \iota_J \otimes \iota_N + \kappa \otimes \iota_T + \psi \iota_J + \iota_N \otimes \omega + \nu$$

where $\eta = (\eta_1, \ldots, \eta_N)'$, $\kappa = (\kappa_1, \ldots, \kappa_N)'$, $\psi = (\psi_1, \ldots, \psi_N)'$, $\nu = (\nu_1, \ldots, \nu_N)'$, ι_N is a N column vector of ones.

Let us assume $\eta_i \sim IID(0, \sigma_\eta^2)$, $\mu_j \sim IID(0, \sigma_\mu^2)$, $\theta_t \sim IID(0, \sigma_\theta^2)$, $\kappa_{ij} \sim IID(0, \sigma_\kappa^2)$, $\psi_{it} \sim IID(0, \sigma_\psi^2)$, $\omega_{jt} \sim IID(0, \sigma_\omega^2)$, $\nu_{ijt} \sim IID(0, \sigma_\nu^2)$ are independent of each other. We can calculate the variance-covariance matrix

$$\begin{aligned}
\Omega &= E[\varepsilon\varepsilon'] \\
&= E[(\eta \iota_J \iota_T + \iota_N \otimes \mu \otimes \iota_T + \theta \otimes \iota_J \otimes \iota_N + \kappa \otimes \iota_T + \psi \iota_J + \iota_N \otimes \omega + \nu) \\
&\qquad (\eta \iota_J \iota_T + \iota_N \otimes \mu \otimes \iota_T + \theta \otimes \iota_J \otimes \iota_N + \kappa \otimes \iota_T + \psi \iota_J + \iota_N \otimes \omega + \nu)'] \\
&= E[\eta\eta' \otimes D_J \otimes D_T + D_N \otimes \mu\mu' \otimes D_T + D_N \otimes D_J \otimes \theta\theta' \\
&\qquad + \kappa\kappa' \otimes D_T + \psi\psi' \otimes D_J + D_N \otimes \omega\omega' + \nu\nu']
\end{aligned}$$

$$\begin{aligned}
\Omega = \quad & \sigma_\eta^2 \quad I_N \quad \otimes D_J \quad \otimes D_T \\
& + \sigma_\mu^2 \quad D_N \quad \otimes I_J \quad \otimes D_T \\
& + \sigma_\theta^2 \quad D_N \quad \otimes D_J \quad \otimes I_T \\
& + \sigma_\kappa^2 \quad I_N \quad \otimes I_J \quad \otimes D_T \\
& + \sigma_\psi^2 \quad I_N \quad \otimes D_J \quad \otimes I_T \\
& + \sigma_\omega^2 \quad D_N \quad \otimes I_J \quad \otimes I_T \\
& + \sigma_\nu^2 \quad I_N \quad \otimes I_J \quad \otimes I_T
\end{aligned}$$

where I_N, I_J, I_T are identity matrices of order N, J, T, and D_N, D_J, D_T are square matrices of ones of order N, J, T.

Employing Wansbeek and Kapteyn (1982, 1983), define the averaging operators $\overline{D}_T = D_T/T$, $\overline{D}_J = D_J/J$, $\overline{D}_N = D_N/N$, and the centering operators $A_T = I_T - \overline{D}_T$, $A_J = I_J - \overline{D}_J$, $A_N = I_N - \overline{D}_N$. Substitution gives

$$
\begin{aligned}
\Omega = \quad & JT\sigma_\eta^2 && (A_N + \overline{D}_N) && \otimes \overline{D}_J && \otimes \overline{D}_T \\
& +NJ\sigma_\theta^2 && \overline{D}_N && \otimes \overline{D}_J && \otimes (A_T + \overline{D}_T) \\
& +NT\sigma_\mu^2 && \overline{D}_N && \otimes (A_J + \overline{D}_J) && \otimes \overline{D}_T \\
& +T\sigma_\kappa^2 && (A_N + \overline{D}_N) && \otimes (A_J + \overline{D}_J) && \otimes \overline{D}_T \\
& +J\sigma_\psi^2 && (A_N + \overline{D}_N) && \otimes \overline{D}_J && \otimes (A_T + \overline{D}_T) \\
& +N\sigma_\omega^2 && \overline{D}_N && \otimes (A_J + \overline{D}_J) && \otimes (A_T + \overline{D}_T) \\
& +\sigma_\nu^2 && (A_N + \overline{D}_N) && \otimes (A_J + \overline{D}_J) && \otimes (A_T + \overline{D}_T)
\end{aligned}
$$

Define a $T \times (T-1)$ matrix G as $G_T G_T' = A_T$, $G_T' G_T = I_{T-1}$, $\iota_T' G_T = 0$. Define $\bar{\iota}_T = T^{-1/2}\iota_T$. Hence columns of G_T are a set of *(T-1)* eigenvectors of A_T, $\bar{\iota}_T$ corresponds with its only zero eigenvalue, $\bar{\iota}_T$ is the eigenvector of $\overline{J}_T$ corresponding with its only non-zero eigenvalue, the columns of G_T with its *(T-1)* zero values. Collecting terms in the same matrices yields the spectral decomposition

$$
\Omega = \begin{pmatrix}
G_N \otimes G_J \otimes G_T \\
G_N \otimes G_J \otimes \bar{\iota}_T \\
G_N \otimes \bar{\iota}_J \otimes G_T \\
G_N \otimes \bar{\iota}_J \otimes \bar{\iota}_T \\
\bar{\iota}_N \otimes G_J \otimes G_T \\
\bar{\iota}_N \otimes G_J \otimes \bar{\iota}_T \\
\bar{\iota}_N \otimes \bar{\iota}_J \otimes G_T \\
\bar{\iota}_N \otimes \bar{\iota}_J \otimes \bar{\iota}_T
\end{pmatrix}' diag \begin{pmatrix}
\xi_1 \; I_{(N-1)(J-1)(T-1)} \\
\xi_2 \; I_{(N-1)(J-1)} \\
\xi_3 \; I_{(N-1)(T-1)} \\
\xi_4 \; I_{(N-1)} \\
\xi_5 \; I_{(J-1)(T-1)} \\
\xi_6 \; I_{(J-1)} \\
\xi_7 \; I_{(T-1)} \\
\xi_8
\end{pmatrix} \begin{pmatrix}
G_N \otimes G_J \otimes G_T \\
G_N \otimes G_J \otimes \bar{\iota}_T \\
G_N \otimes \bar{\iota}_J \otimes G_T \\
G_N \otimes \bar{\iota}_J \otimes \bar{\iota}_T \\
\bar{\iota}_N \otimes G_J \otimes G_T \\
\bar{\iota}_N \otimes G_J \otimes \bar{\iota}_T \\
\bar{\iota}_N \otimes \bar{\iota}_J \otimes G_T \\
\bar{\iota}_N \otimes \bar{\iota}_J \otimes \bar{\iota}_T
\end{pmatrix}
$$

In more compact notation

$$\Omega = \sum_{r=1}^{8} \xi_r M_r$$

where eigenvalues ξ_r and projectors M_r are defined in table 8

Table 8 Eigenvalues and eigenvectors of Ω

r	ξ_r	eigenvector	M_r	rank
1	σ_ν^2	$G_N \otimes G_J \otimes G_T$	$A_N \otimes A_J \otimes A_T$	$(N-1)(J-1)(T-1)$
2	$\sigma_\nu^2 + T\sigma_\kappa^2$	$G_N \otimes G_J \otimes \bar{\iota}_T$	$A_N \otimes A_J \otimes \overline{D}_T$	$(N-1)(J-1)$
3	$\sigma_\nu^2 + J\sigma_\psi^2$	$G_N \otimes \bar{\iota}_J \otimes G_T$	$A_N \otimes \overline{D}_J \otimes A_T$	$(N-1)(T-1)$
4	$\sigma_\nu^2 + \sigma J_\psi^2 + T\sigma_\kappa^2 + JT\sigma_\eta^2$	$G_N \otimes \bar{\iota}_J \otimes \bar{\iota}_T$	$A_N \otimes \overline{D}_J \otimes \overline{D}_T$	$(N-1)$
5	$\sigma_\nu^2 + N\sigma_\omega^2$	$\bar{\iota}_N \otimes G_J \otimes G_T$	$\overline{D}_N \otimes A_J \otimes A_T$	$(J-1)(T-1)$
6	$\sigma_\nu^2 + N\sigma_\omega^2 + T\sigma_\kappa^2 + NT\sigma_\mu^2$	$\bar{\iota}_N \otimes G_J \otimes \bar{\iota}_T$	$\overline{D}_N \otimes A_J \otimes \overline{D}_T$	$(J-1)$
7	$\sigma_\nu^2 + N\sigma_\omega^2 + J\sigma_\psi^2 + NJ\sigma_\theta^2$	$\bar{\iota}_N \otimes \bar{\iota}_J \otimes G_T$	$\overline{D}_N \otimes \overline{D}_J \otimes A_T$	$(T-1)$
8	$\sigma_\nu^2 + N\sigma_\omega^2 + J\sigma_\psi^2 + T\sigma_\kappa^2 + NT\sigma_\mu^2 + JT\sigma_\eta^2 + NJ\sigma_\theta^2$	$\bar{\iota}_N \otimes \bar{\iota}_J \otimes \bar{\iota}_T$	$\overline{D}_N \otimes \overline{D}_J \otimes \overline{D}_T$	1

The transformations corresponding to the various projectors are

$$
\begin{aligned}
(M_1 y)_{ijt} &= +y_{ijt} - y_{ij.} - y_{i.t} - y_{.jt} + y_{i..} + y_{.j.} + y_{..t} - y_{...} \\
(M_2 y)_{ijt} &= +y_{ij.} - y_{i..} - y_{.j.} + y_{...} \\
(M_3 y)_{ijt} &= +y_{i.t} - y_{i..} - y_{..t} + y_{...} \\
(M_4 y)_{ijt} &= +y_{i..} - y_{...} \\
(M_5 y)_{ijt} &= +y_{.jt} - y_{.j.} - y_{..t} + y_{...} \\
(M_6 y)_{ijt} &= +y_{.j.} - y_{...} \\
(M_7 y)_{ijt} &= +y_{..t} - y_{...} \\
(M_8 y)_{ijt} &= +y_{...}
\end{aligned}
$$

On combining these we obtain

$$
\begin{aligned}
(\Omega^a y)_{ijt} = & \xi_1^a y_{ijt} \\
& + (\xi_2^a - \xi_1^a) y_{ij.} + (\xi_3^a - \xi_1^a) y_{i.t} + (\xi_5^a - \xi_1^a) y_{.jt} \\
& + (\xi_4^a - \xi_3^a - \xi_2^a + \xi_1^a) y_{i..} + (\xi_6^a - \xi_5^a - \xi_2^a + \xi_1^a) y_{.j.} + (\xi_7^a - \xi_5^a - \xi_3^a + \xi_1^a) y_{..t} \\
& + (\xi_8^a - \xi_7^a - \xi_6^a - \xi_4^a + \xi_5^a + \xi_3^a + \xi_2^a - \xi_1^a) y_{...}
\end{aligned}
$$

Hence we can obtain GLS as WLS.

Working Paper

95-01 Christian Belzil: Contiguous Duration Dependence and Nonstationarity in Job Search

95-02 Christian Belzil: Unemployment Insurance and Unemployment Over Time: An Analysis with Event History Data.

95-03 Christian Belzil: Unemployment Duration Stigma and Reemployment Earnings.

95-04 Christian Belzil: Relative Efficiencies and Comparative Advantages in Job Search.

95-05 Niels Henning Bjørn: Causes and Consequences of Persistent Unemployment.

95-06 Nicholas M. Kiefer and Mark F.J. Steel: Bayesian Analysis of the Prototypal Search Model.

95-07 Nicholas M. Kiefer, Ranjini Natarajan and Charles E. McCulloch: Maximum Likelihood for the Multinomial Probit Model.

95-08 Christian Belzil and Philip Hergel: Fertility and the Human Capital Loss of Non-Participation

95-09 Christian Belzil, William A. Sims and Philip Hergel: Endogeneity, Self-Selectivity and the Sensitivity of Female Earnings to Non-Participation.

95-10 Paul Bingley, Niels Henning Bjørn and Niels Westergård-Nielsen: Wage Mobility in Denmark 1980-1990.

95-11 Audra J. Bowlus, Nicholas M. Kiefer and George R Neumann: Estimation of Equilibrium Wage Distributions with Heterogeneity.

95-12 Anders Björklund and Tor Eriksson: Unemployment and Mental Health: Evidence from Research in the Nordic Countries

Gustav Wieds Vej 10C Phone: +45 8942 2350 Email: cls@cls.dk

DK-8000 Århus C Fax: +45 8942 2365 WWW: http://www.cls.dk

Working Paper

95-13 Melvyn G. Coles and John G. Treble: Here Today, Gone Tomorrow: Calculating the Price of Worker Reliability.

95-14 Christian Belzil: Employment Reallocation, the Return to Human Capital and the Allocation of Workers Between Expanding and Declining Firms.

95-15 John T. Addison and Jean-Luc Grosso: Job Security Provisions and Employment: Revised Estimates.

95-16 John T. Addison and McKinley L. Blackburn: A Puzzling Aspect of the Effect of Advance Notice on Unemployment.

95-17 Peder J. Pedersen and Nina Smith: The Welfare State and the Labour Market.

95-18 Mette Lausten: Inter-Industry Wage Differentials in Denmark ?

96-01 Mark Yuying An: Log-concave Probability Distributions: Theory and Statistical Testing.

96-02 Audra Bowlus, Nicholas M. Kiefer and George R. Neumann: Fitting Equilibrium Search Models to Labour Market Data.

96-03 Karsten Albæk, Mahmood Arai, Rita Asplund, Erling Barth and Erik Strøyer Madsen: Employer Size-Wage Effects in the Nordic Countries.

96-04 Bent J. Christensen and Nicholas M. Kiefer: Inference in Non-Linear Panels with Partially Missing Observations: The Case of the Equilibrium Search Model.

96-05 Michèle Naur and Nina Smith: Cohort Effects on the Gender Wage Gap in Denmark.

96-06 Elizabeth J. Cunningham: The Relationship between Recruiting and Screening within the Employer Search Framework

96-07 Tim Barmby and Nina Smith: Household Labour Supply in Britain and Denmark: Some Interpretations Using a Model of Pareto Optimal Behaviour.

96-08 Michael Rosholm: Unemployment Duration over the Business Cycle.

96-09 Mark Yuying An and Ming Liu: Structural Analysis of Labor Market Transitions Using Indirect Inference

Gustav Wieds Vej 10C Phone: +45 8942 2350 Email: cls@cls.dk
DK-8000 Århus C Fax: +45 8942 2365 WWW: http://www.cls.dk

Working Paper

96-10 Paul Bingley and Niels Westergård-Nielsen: Worker and Plant Wages: Estimates from a Multi-Level Model

96-11 Paul Bingley and Gauthier Lanot: Danish Private Sector Wage Policies and Male Retirement Decisions

96-12 George R. Neumann and Gauthier Lanot: Measuring Productivity Differences in Equilibrium Search Models.

96-13 Tor Eriksson: Executive Compensation and Tournament Theory: Empirical Tests on Danish Data.

96-14 Peter Jensen and Helena Skyt Nielsen: Child Labour or School Attendance ? Evidence from Zambia.

96-15 Ebbe Krogh Graversen: Male and Female Labour Supply in Denmark.

96-16 Tor Eriksson and Markus Jäntti: The Distribution of Earnings in Finland 1971-1990.

96-17 Ebbe Krogh Graversen: Measuring Labour Supply Responses to Tax Changes by Use of Exogenous Tax Reforms.

97-01 Report 1993 - 1996.

97-02 Paul Bingley and Ian Walker: Labour Supply with In-Work and In-Kind Transfers.

97-03 Paul Bingley and Ian Walker: Household Unemployment and the Labour Supply of Married Women.

97-04 Christian Belzil: Job Creation and Destruction, Worker Reallocation and Wages.

97-05 Christian Belzil: The Dynamics of Female Time Allocation upon a First Birth

97-06 Christian Belzil and Jörgen Hansen: Estimating the Returns to Education from a Non-Stationary Dynamic Programming Model

97-07 Niels Westergård-Nielsen and Anders Rue Rasmussen: Apprenticeship Training in Denmark - the impacts of subsidies.

Gustav Wieds Vej 10C Phone: +45 8942 2350 Email: cls@cls.dk
DK-8000 Århus C Fax: +45 8942 2365 WWW: http://www.cls.dk

97-08 H. Bunzel, B.J. Christensen, P. Jensen, N.M. Kiefer, L. Korsholm, L. Muus, G.R. Neumann, M. Rosholm: Specification and Estimation of Equilibrium Search Models.

97-09 Ebbe Krogh Graversen: Work disincentive effects of taxes among Danish married men and women

97-10 Jukka Vittaniemi: Top Executive Compensation and Company Performance in Finland.

97-11 Peder J. Pedersen and Nina Smith: Trends in the Danish Income Distribution, 1976-90.

97-12 Ronald L. Oaxaca and Michael R. Ransom: Identification in Detailed Wage Decompositions

97-13 Bent J. Christensen and Nicholas M. Kiefer: Panel Data, Local Cuts and Orthogeodesic Models

97-14 Michael Rosholm: The risk of marginalization in the labour market: Application of a three state dependent competing risks duration model.

97-15 Helena Skyt Nielsen and Michael Rosholm: The Incidence of Unemployment: Identifying Quits and Layoffs

97-16 Tor Eriksson: Long-Term Earnings Mobility of Low-Paid Workers

97-17 Lars Korsholm: The Semiparametric Normal Variance-Mean Mixture Model

98-01 Helena Skyt Nielsen: Two Notes on Discrimination and Decomposition

98-02 Esben Agerbo, Tor Eriksson, Preben Bo Mortensen and Niels Westergård-Nielsen: Unemployment and mental disorders - an empirical analysis

98-03 Birthe Larsen: Minimum Wages, Technological Progress and Loss of Skill

98-04 Kevin T. Reilly and Tony S. Wirjanto: Does More Mean Less ? The Male/Female Wage Gap and the Proportion of Females at the Establishment Level

Gustav Wieds Vej 10C Phone: +45 8942 2350 Email: cls@cls.dk
DK-8000 Århus C Fax: +45 8942 2365 WWW: http://www.cls.dk

ISSN 0908-8962

CENTRE FOR LABOUR MARKET AND SOCIAL RESEARCH

Science Park Aarhus, Gustav Wieds Vej 10C, 8000 Aarhus C, Denmark

Phone: +45 8942 2350 Fax: +45 8942 2365 Email: cls@cls.dk WWW: http://www.cls.dk

CLS is funded by The Danish National Research Foundation