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A Latent Variable Approach to Examining the Effects of HR Policies on the Inter- and Intra-Establishment Wage and Employment Structure: A Study of Two Precision Manufacturing Industries

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1. Introduction

Studies over the last two decades make clear that firms' attempts to remain competitive in a global economy have taken them in many different directions. The proliferation of strategies has thrown into relief patterns by which differences in the wage structure of establishments appear to be associated with the ways they are organizing work and implementing new technologies. Increasing wage variation within industries during the eighties and nineties was clearly associated with attempts by organizational decision makers to adopt new technologies (Doms, Dunn, and Troske, 1997), shift the composition of the workforce to more highly skilled workers (Berman, Bound, and Griliches, 1994), and implement coherent systems of worker incentives consistent with the increasingly indirect nature of work associated with new information technologies and with increasing imperatives for quality and productivity (Marshall, 1994).[1]

Among more recent studies, Lazear and Shaw (2008) have found that inter-firm differences in pay levels have both continued to grow over time, and are clearly correlated with measures of within-firm wage variation, signaling the importance of differences among firms' internal pay strategies. The research program of 'Insider Econometrics' (Ichniowski and Shaw, 2009), is dedicated to answering questions including - What accounts for the differences in strategies? How do firms/establishments using policies in very different ways differ? How do these differences among firms/establishments account for differences in performance? Are groups of workers affected equally or differently ? What types of skills are targeted?

The more limited focus of the current study asks – How does the wage and employment structure of establishments using policies in very different ways differ? Are groups of workers affected equally or differently? What types of skills are targeted? The study addresses these questions using a variety of detailed measures of the wage structure of establishments that include measures designed to co-vary with establishments' usage of particular types of HR wage policies aimed at increasing qualitative flexibility. The study uses latent variable techniques to identify a latent construct underlying the inter-correlation between these content-laden measures of the wage structure, the establishment wage differential, the detailed occupational wages previously shown to be

[1] Berman, Bound, and Griliches (1994), Autor, Katz, and Krueger (1997), and Berndt, Morrison, and Rosenblum (1992) all found that increases in non-production workers' share of the industry wage bill over the 1980s were positively related to both changes in capital intensity and to various measures of high-tech capital usage. See Machin and Van Reenen (1998) for a similar analysis of OECD countries.

most highly correlated with these other measures of the wage structure, and the employment intensities of those occupations previously shown to be 'discriminators' between high and low wage establishments.

The analyses are aimed at uncovering the causal factors underlying the pattern by which the wages and employment of particular types of occupations are correlated with the establishment wage differential. Previous studies by this author (Osburn, 2000) have shown that those occupational wages most highly correlated with the establishment wage differential are those occupations most directly involved in the primary activities of the establishment, and those most directly involved in the most technically complex activities.

The analyses borrow elements from a variety of recent studies. First, the analyses use data on establishments in narrowly defined industry/establishment size groupings. 'Insider Econometrics' focuses on groups of establishments, all using a narrowly defined production process, to build up a detailed understanding of their internal practices and of the productivity effects of those practices, based on intensive interviews in conjunction with measures of organizational performance. The studies make clear that many of the causal mechanisms by which particular types of policies succeed or fail are only visible by holding the production function constant. Nonetheless, many of the results have been readily generalized to other production processes. In the current study, the analyses are conducted within detailed industry /establishment size cells in an attempt to hold constant many of these same factors.

Second, Kremer and Maskin (1996) pioneered the use of a measure of the wage structure of the establishment as a measure of HR wage policy. The Kremer-Maskin segregation index is designed to co-vary with the degree of worker 'sorting' in the establishment, defined as the degree to which the establishment pays all workers a uniform differential above or below the market wage for his or her measured skills.[2] The degree of worker sorting increases as a by-product of certain types of HR wage policies, and is often an explicit policy in large establishments with a particular focus on quality.

The Kremer-Maskin segregation index suggests other, similar measures.[3] Another measure, specially devised for this study, is designed to co-vary with establishments' usage of pay-for-performance-type policies and is termed 'WOBO'. These two content-laden measures of the establishment wage structure are subsequently referred to as wagestruc^{p}.

Finally, the studies focused on the Precision Manufacturing sector as a means of assuring that the establishments examined face considerable ongoing pressures to boost quality and productivity. Pil and Macduffie (1996) found that such plants are more likely to adopt both flexible automation and high involvement work practices.

The studies combine these elements to show that measures of the wage structure of establishments operating in a very similar production environment convey a great deal of

[2] The Kremer-Maskin segregation index is here applied to individual establishments, but has general applicability.

[3] See Kremer (1993) for detailed discussion of the worker sorting hypothesis.

information about the differences among the establishments in the group.

Data available from the Bureau of Labor Statistics' Occupational Employment Statistics (OES) Survey are especially well suited to the analyses, due to the collection of wage data for all workers in the establishment, as is required to produce measures of the establishment wage structure, and its large size and high degree of industrial and occupational detail, such that relationships between the wages or employment of detailed occupations and other variables can be examined even within detailed industries. Two sets of studies use the OES data for establishments in the precision manufacturing industries Aircraft Parts (non-engine) Manufacturing and Medical Device Manufacturing.

A mixed continuous/discrete latent variable model is used to examine a latent construct defined by the inter-correlation between 1) those occupational wages that are most highly correlated with measures of the establishment wage structure, 2) the employment intensities of one or more detailed 'discriminator' occupations, 3) the establishment wage differential, and 4) the measure $wagestruc^{p}$. In both studies, the occupational wages most highly correlated with measures of the wage structure of the establishment include occupations directly involved in ensuring quality, including Inspectors, and in both studies, the 'discriminator' occupations include occupations most directly involved in the most technically complex activities.

The results for the group of midsize Aircraft Parts manufacturers show that a latent construct identified by the shared variance between 'WOBO', the wages of Inspectors, the wages of Team Assemblers, and the employment share of Machinists explains a considerable percentage of the inter- and intra-establishment wage variance within the industry /size cell, as well as a considerable share of the variance of each of the detailed occupational wage /employment variables. The results for a group of large Medical Device manufacturers show that a latent construct identified by the shared variance between the Kremer-Maskin Segregation index, the wages of Inspectors, the establishment wage differential, and the employment share of Biomedical Engineers explains a considerable percentage of the inter- and intra-establishment wage variance within the industry /size cell, as well as a considerable share of the variance of each of the detailed occupational wage /employment variables.

The results are consistent with the notion that policies including pay for performance and worker sorting are targeted toward those occupations most directly involved in ensuring the quality of the product, and are associated with larger employment intensities of particular occupations engaged in the most technically complex activities at the core of the production process.

The following section describes the OES dataset. Section three briefly reviews recent studies examining the relationship between the inter- and intra-establishment wage and employment structure and usage of HR policies aimed at increasing qualitative flexibility. Section three also discusses the recent generalization of latent variable modeling that has expanded the range of problems for which it is useful to include the mixed discrete/continuous model examined here. Section four describes the model, data, and variables. Section five discusses the estimation and evaluation of the model. Section six discusses the results. Section 7 re-examines recent findings of Lazear and Shaw (2008), whose measures of within-establishment wage variance did not benefit from the occupational detail made possible in the current study by use of the OES data. Section 8 offers some conclusions and directions for further study.

2. The Occupational Employment Statistics Survey Data

The OES Survey collects data on the detailed occupation and wage category of each employee in approximately 1.2 million establishments spanning the non-farm private and public sectors. The data are collected by mail survey over a three year cycle using six biannual collection panels. A random sample stratified by State /Area /4 or 5 digit NAICS Industry /Establishment size is used to select the establishments, and each worker is classified into an occupation using the approximately 800 categories of the Standard Occupational Classification. The wage data are collected in 12 wage intervals.[4]

The OES data are an important resource for studies in the mold of 'Insider Econometrics' due to the collection of wage and employment data for all employees in very large number of establishments.

3. Literature Review

A large literature now documents findings that a substantial portion of the churning in labor markets over recent decades has occurred within industries; increases in earnings variance, occupational upgrading, and a proliferation of strategies for the internal organization of the establishment including the implementation of new technologies have all occurred within industries.[5] During the most recent period, increasing wage variance within industries appears to be related to both increasing inter- and *intra*-establishment wage variance, reflecting both differences among firms/establishments in the way they are valuing workers' skills and changes in the way they are compensating individual workers.

Lazear and Shaw (2008) found that inter-firm differences in pay levels have not only continued to grow over time, but are also clearly correlated with measures of within-firm wage variance in each of a group of countries including Scandinavian and European countries and the U.S. In each, within-firm wage variance in fact accounts for a whopping 60-80% of total wage variance. These findings are also mirrored in the pattern of wage growth within firms; within-firm dispersion of wage growth is very often twice that of the mean wage growth of the firm.

Further, Lazear and Shaw found that the dispersion of wage growth within firms mirrors the pattern of wage growth across individuals and firms in the economy generally.

[4] The wage interval midpoints in the OES Survey are estimated using data from the Bureau of Labor Statistics' National Compensation Survey.
[5] See Wever, Kirsten 1995. Chapter 1 for discussion of the US institutional framework of labor/management relations and the causal dynamics of this proliferation.

While Lazear and Shaw's first set of findings would seem to reflect correlation between firms' wage levels and their usage of wage policies such as pay-for-performance, Lazear and Shaw note an alternative explanation that must be examined. Such findings could be a statistical artifact created by worker sorting, wherein sorting by ability results in high wage firms having higher wage variance due to the skewness of the overall wage distribution near the top.[6]

3.1 Increasing inter- and intra-establishment wage variance and HR policies aimed at increasing quality and productivity

Inter-establishment wage differentials refer to differences between establishments in the wages of otherwise similar workers, meaning (in this study) workers in a given industry, establishment size, and occupation, but different establishment[7]. Wage differentials between establishments result from unmeasured differences in labor quality, unmeasured differences in establishment characteristics, differences in establishment pay and human resource policies, and the role of frictional or structural elements in the environment of the establishment that result in differing wage/training/technology usage outcomes.[8]

Due to a lack of adequate datasets, there exist relatively few studies that attempt to examine the relationship between establishment wage levels and measures of their internal practices, including their usage of HR policies aimed at boosting quality and productivity. Osterman (2006) summarizes the channels through which a bundle of practices including self-managed teams, quality programs, and job rotation (together termed high-performance work organization, or HPWO) raise wages. HPWO practices raise wages 1) by raising the return to, and demand for skill, leading to changes in hiring and/or training practices, 2) through their association with investments in new technology that do the same, 3) by raising firm performance and thus the ability to pay higher wages, and 4) by increasing workers' relative power in the wage bargain, as firms increasingly depend on systems based on raising workers' levels of intrinsic motivation. Using establishment level data on core (production) workers in manufacturing plants, Osterman found that usage of HPWO is associated with establishment wage levels that are higher by about four percent. Osterman (2006) and Cappelli and Newmark (2001), both found that HPWO are associated with higher labor costs per worker, after controlling for skills and labor quality.

Gittleman and Mandel (2004) provide a detailed discussion of the avenues through which HPWO practices may lead to increases in the wages establishments. Using data from the Survey of Employer Provided Training, they however found that HPWO practices have little effect on the wages of either establishments or of the wages of occupations thought to be most directly targeted by those policies.

There exist even fewer studies on the effects of HR policies on the distribution of wages

[6] See discussion in Lazear and Shaw (2008).

[7] Groshen (1991) found that occupation /establishment together account for up to 90% of wage variance among production workers.

[8] See Groshen (1999) for a survey of explanations of inter-establishment wage differentials.

within establishments. Osterman (2006) notes that both pay-for-performance policies and skill-biased technological change serve to increase wage variance within establishments, while implementation of job rotation and cross training should, on the other hand, reduce intra-establishment wage variance. Lindbeck and Snower (2000) suggest that implementation of HPWO policies should give rise to increases in wage variance among those employees that work directly within them, as differences in workers' relative performance within such systems become apparent.

Differences in the ways firms are implementing HR policies and new technologies reflect to some degree the difficulty and uncertainty of the task facing firms. On one hand, complex complementarities between organizational practices give rise to the need for comprehensive redesign of their employment systems if substantial increases in quality and productivity are to be realized. Problem solving teams, which boost productivity by exploiting complementarities between a diverse range of high-level skills, are successful in organizations that have both tough, short term problems to deal with, and succeed in "changing the fabric of the environment" of the organization, toward one that maximizes workers' incentives to cooperate with other members of the team.[9] Policies that encourage worker cooperation, including group-based incentives and pay compression, are in turn dependent on open, highly developed communication channels.[10] Policies that govern mobility paths within the firm are also important. Mobility paths that route workers into the managerial ranks on the basis of many of the same skills, knowledge, and abilities as other workers instill intrinsic motivation by conferring status on workers, as a locus of commitment and competence in the organization. Self-directed teams accomplish much of the same by offering employees opportunities to contribute discretionary effort. Bailey, Berg, and Sandy (2001) suggest that this shift toward policies aimed at enhancing intrinsic motivation is the central feature of the high-performance (now termed high-involvement) work organization. In the largest establishments, decision makers often develop stringent selection criteria in an effort to hire the right 'type' of workers, for whom intrinsic motivation is an actual goal of work. In these establishments, the resulting 'explicit' worker sorting effects augment worker self-sorting effects that result from pay-for-performance policies, as many of the lowest performing workers opt out of establishments that use them.[i]

Use of explicit worker sorting policies is especially important in production environments for which mistakes are highly costly. Kremer (1993) describes important complementarities that exist between workers with similar skill levels in such establishments. The title of Kremer's paper, "The O-Ring Theory of Economic Development", references the sad example of the seemingly insignificant engineering flaw implicated in the US space shuttle Challenger disaster in 1986. When quality is important, the production function is often characterized by a positive cross derivative of output in the returns to different workers' skill levels; the increase in output from an increase in one worker's skill level is a positive function of the skill levels of his co-workers. Especially in larger establishments, such production functions account for a high degree of worker sorting, wherein the wage of each employee falls within a similar percentage deviation from the market wage for his/

[9] See discussion in Ichniowski and Shaw (2009) and Boning, Ichniowski, and Shaw (2001).
[10] See discussion in Murphy (2008).

her occupation/measured skills. The Kremer-Maskin segregation index is a measure of the degree of worker sorting, and is one of the two wagestruc[p] used in this paper.

Complementarities between practices also account for vast differences in the ways firms are implementing new technologies. Bresnahan, Brynjolfsson, and Hitt (BBH, 1999) argue that a range of organizational outcomes may be related to decision makers' success or failure in recognizing the complex complementarities that exist between particular ways of employing microprocessor technology, the structure of decision making in the organization, and the skill level of the workforce. BBH describe complementarities between human judgment and the enormous storage and retrieval capacities of microprocessor technology, between decentralization of decision making and the enormous increases in information made available, and between human creative intelligence and the greatly expanded creative opportunities made possible by the technologies. According to BBH, these complementarities demand extraordinary management and technical skill.

On the other hand, strong forces of organizational inertia make comprehensive change very difficult. Factors in the environment of the organization including the macro-regulatory institutional structure, industry-specific regulations or quality standards, capital intensity, the particular training, experience, and values of managers, or the historical role of workers in the production process, all become embedded in the culture and functioning of organizations in ways that are very difficult to change.[11] Haltiwanger, Lane, and Spletzer (2007) documented the remarkable persistence of such differences over a decade or more, using a matched employee-employer longitudinal dataset. They suggest that organizations' capabilities for comprehensive change appear to be a function of "inherently difficult to measure characteristics such as managerial ability or related organizational practices".

The resulting pattern has led some to characterize 'types' of firms/establishments that succeed or fail at attempts to implement comprehensive changes resulting in coherent systems of work and worker incentives. 'Type I' establishments adopt a host of complementary HR practices that build efficiencies into each stage of production and reward workers in ways that maximize intrinsic motivation, while 'type II' establishments appear to be rooted in an older philosophy and set of assumptions, more characteristic of an assembly line mass production environment. 'Type I' establishments compete on the basis of quality and productivity, while 'type II' establishments tend to compete more on the basis of cutting costs.[12] Haltiwanger, Lane, and Spletzer (2007) suggest that much within-industry churning can be described by the interplay between firm 'type', the process of organizational learning, and the resulting choice of worker/skill mix and ultimate success or failure of individual firms. The research program of 'Insider Econometrics' (Ichniowski and Shaw, 2009) is devoted to developing a detailed understanding of how and why 'Type I' versus 'Type II' firms /establishments succeed or fail at implementing HR policies in ways that have clear, positive effects on organizational performance.

[11] See Michael T. Jacobs (1992), Kirsten Wever (1995), and John Dunlop (1958).
[12] For an early example, see Kline (1988).

3.2 Measures of the establishment wage structure as proxy measures of HR policy

The Kremer-Maskin segregation index provides a link between the wage structure of the establishment and the degree of effective worker sorting in the establishment. As already mentioned, pay for performance policies induce a certain amount of implicit worker sorting that is often augmented by explicit worker sorting in many large establishments. These patterns account for the dominance of worker sorting effects on the wage structure of large establishments in the manufacturing sector, while the direct effects of pay for performance policies, of raising within-establishment wage variance, tend to dominate the wage structure in small and mid-size establishments.

These considerations determine the choice of the $wagestruc^{p}$ measure for the two analyses. For the group of large establishments in the Medical Device Manufacturing sector, the Kremer-Maskin segregation index is used as the $wagestruc^{p}$. For the group of mid-size establishments in the Aircraft Parts Manufacturing sector, the study uses a measure termed 'WOBO' that is designed to covary with establishments' usage pay-for-performance policies. The Kremer–Maskin segregation index and the measure WOBO are discussed in detail in Section 4.1.

3.3 Generalized Latent Variable Modeling

Both the measure WOBO and the Kremer-Maskin segregation index (KM) confound together all of the myriad factors that impact the wage structure within and between establishments. The use of latent variable techniques goes some way toward untangling these separate effects by isolating only the shared variance between the $wagestruc^{p}$, the establishment wage differential, and the detailed occupational wages and employment intensities most closely associated with it. The remaining residual variance is then treated as measurement error. The known characteristics of the detailed occupations and of the $wagestruc^{p}$ in this inter-correlated set then provide the basis for inferring the nature of the causal forces they mirror. A good model completely explains the dependence between the measurements on a given subject, such that the measurement items are 'conditionally independent' given the latent variable.

The use of latent variable techniques is often motivated by the complexity of social interaction and the vast array of organizational outcomes that we suspect are molded by the characteristics of that interaction. Latent variable techniques are especially important for attempts to explain differences in organizational outcomes among otherwise very similar organizations or establishments, where we suspect that unobserved heterogeneity in the form of differing organizational cultures or differences in managers' 'model' of worker behavior are driving forces.

The incorporation into the analyses of portions of the employment structure of the establishment make use of recent advances that have generalized latent variable techniques to allow, among other innovations, mixed continuous/discrete data types. These stem from the generalization of multilevel modeling, the recognition of the equivalencies between multilevel modeling and more traditional Structural Equation

Modeling (SEM), and from the reformulation of the generalized linear model.

Complex variance structures such as arise in longitudinal or spatial analyses, or analyses of relationships within and between organizations can very often be described in terms of nested 'levels' in the data. Multilevel models are based on this simple relationship; they account for complex variance structures by explicitly modeling them in terms of level 1 units, level 2 units.[13]

One key to the generalization of latent variable modeling has been the application of the multilevel modeling concept of 'exchangeability' between level one units to the role played by the assumption of multivariate normality in traditional SEM.[14] Given a well fitting model, both assumptions imply conditional independence, independence of the measurement items conditional on the latent variable. In the maximum likelihood framework of multilevel modeling, this assumption simplifies the likelihood function to a simple Cartesian product of the contributions of each variable in the analysis. In practice, we easily relax the assumption of exchangeability in favor of 'partial exchangeability' thus allowing the model for each measurement item to differ in terms of both its coefficient on the latent variable, or 'factor loading', and its residual variance.

A second key innovation has been the reformulation of the generalized linear model (GLM) to allow the application of multilevel modeling techniques, opening the way for the joint modeling of continuous and discrete data types. The traditional GLM framework models the conditional mean by conditioning on the observed data.[15] Heagerty (1999) reformulated the conditional model as one that instead conditions on the latent variable. The reformulated conditional model gives the expected response for different values of the measured covariates, for given values of the latent variable. The familiar generalized linear mixed model optimizes a conditional criterion to estimate the conditional parameters of this model. The more recently developed marginally specified generalized linear model, or 'marginalized latent variable model', instead optimizes a marginal likelihood produced by integrating the conditional likelihood function over the distribution of the random effects.[16] Pairing this model structure with the assumption of conditional independence allows the likelihood terms associated with the logit (or probit,etc.) model for the discrete variable to enter the likelihood in the same way as do the continuous variables.

4. A Latent Variable Model of the Establishment Wage and Employment Structure in Two Precision Metal Manufacturing Industries

4.1 The Latent Variable Model

The analyses examine an establishment-level latent variable defined by the joint distribution of measures including the wagestruc^{p}, the establishment wage differential, the

[13] See Rabe-Hesketh et.al.(2004)
[14] See Muthen (2002) for discussion.
[15] For example, see Sammel et.al. (1997).
[16] See discussion in Heagerty and Zeger (2000).

occupational wages that are most highly correlated with these measures, and the employment share of the 'discriminator' occupation(s). This model augments a conventional measurement model for continuous responses to include a binomially distributed employment share variable. Rabe-Hesketh et.al.(2004) have termed this a 'variance components factor model'. In the spirit of Haltiwanger, Lane, and Spletzer (2007), the model envisions this latent variable to be a key indicator of establishment 'type'.[17]

4.1.1 Wage Variables

The measurement items including the establishment wage differential, the occupational wage measures, and either WOBO or the Kremer-Maskin segregation index are each assumed to be normally distributed continuous variables;

1) $y_{ij} = \beta_j + \lambda_j \eta_i + \varepsilon_{ij}$

where j indexes wage variable measurement items and i indexes establishments

$e_{ij} \sim N(0, \psi_j)$ are measurement errors

$\eta_i \sim N(0, \phi)$ is an establishment-level latent variable

λ_j is the factor loading of measurement item j (measures the correlation between the measurement item and the latent variable)

The variance of y_{ij} is composed of two components including the model variance, or the variance due to the latent variable, $\lambda^2 \operatorname{var}(\eta) = \lambda^2 \phi$, and the residual variance ψ_j;

$Var(y) = \lambda_j^{\,2} \phi + \psi_j$

Stacking all into a vector;

2) $Var(y) = \Lambda \Phi \Lambda' + \Psi$

The conditional likelihood of each establishment's continuous measurement item y_{ij} is;

3) $g(y_{ij} \mid \eta_i; \theta_j) = \dfrac{1}{\sqrt{2\pi\psi_j}} \exp\left(\dfrac{-(y_{ij} - \lambda_j \eta_i)^2}{2\psi_j} \right)$

θ_j indexes the parameters λ_j, ψ_j of the model for the wage measures.

[17] The Industrial Relations model (Dunlop, 1958) outlines interdependences between different types of pay policies, mobility paths, and other personnel policies that result in identifiable 'systems' of personnel governance.

4.1.2 Accounting for Structural Missing-ness in the Wage Variables

There exists some evidence that instances of (complete) non-response to the OES Survey are not completely random, especially among large establishments. This issue is not addressed in the current paper, and could have some minor bearing on the results of the analyses for large Medical Device manufacturers, although the effect is likely to lead to understatement rather than overstatement of the results.[18] The OES Survey imputes employment data for non-respondent establishments using hot-deck nearest neighbor methods to select a donor establishment for the occupational employment structure of each establishment. Wage imputation uses a hierarchical set of domains defined by geography /industry /establishment size /occupation to define appropriate cells for the occupational wage distribution. The mean wage distribution of this cell is imputed to the recipient establishment/ occupation cell.

Establishments containing imputed wages were not used in the analyses because, unlike employment imputation, wage imputation in the OES procedures breaks the relationship between establishment identity and systematic wage variation that arises from establishment affiliation.

The OES occupational wage data otherwise exhibit a high degree of structural missing-ness as a result of the existence of large percentages of establishments that do not employ any given occupation that is employed in other establishments in the industry/size cell. Among OES respondents, there exists, in addition, a very small incidence of non-structural missing-ness of individual occupational wage data that is probably not random. The OES Survey imputes wage information in this latter case and not in the former case.

Among the advantages of using maximum likelihood estimation and multilevel modeling techniques for latent variable modeling is the flexibility to easily accommodate both random and structural missing-ness in all variables and to directly test for the role of structural differences in the estimated relationships. In the multilevel modeling framework, missing data are simply handled as unequal size clusters. By contrast, traditional SEM generally requires that all observations have a complete multivariate response in addition to more stringent balance requirements.[19]

4.1.3 The Establishment Employment Share of Machinists (Aircraft Parts Manufacturing) and of Biomedical Engineers (Medical Device Manufacturing)- the 'Factor-Structured Logit'

The latent variable formulation of the logistic regression model assumes that underlying a dichotomous indicator d of whether a given employee in the establishment is a machinist is a continuous latent variable d_i* with residual variance ε that follows a logistic distribution;

[18] See Phipps and Toth (201?)

[19] See discussion in Rabe-Hesketh, Skrondal, Pickles (2004).

$$d_i = 0 \; if \qquad d_i* \le 0$$
$$d_i = 1 \; if \qquad d_i* > 0$$

4) $d_i* = \beta_{0d} + \beta_{1d}' x_i + \varepsilon_{id}$

$\varepsilon_{id} \sim \left(0, \frac{\pi^2}{3}\right),$

The data are summed to counts of the number of machinists per establishment.

The terms $\beta_{0d} + \beta_{1d}' x_i$ include an intercept and the effect of establishment size. The inclusion of the latent variable η in 4) defines the model as a mixed logit;

5) $d_i* = \beta_{0d} + \beta_{1d}' x_i + \lambda_d \eta_i + \varepsilon_{id}$

The mixed logit augments the standard logit with a random intercept. In this study, the model of the employment share of the discriminator occupation is a special type of mixed logit in which the random intercept η is defined by the common variance among the measurement items, and the parameter λ_d is more accurately described as a factor loading. Rabe-Hesketh and Skrondal (2001) have aptly term this model a 'factor-structured' logit.

The inverse of the logit transformation yields the logistic distribution of the probability that a worker is a employed in the discriminator occupation;

$$P_1 = P(d \mid \eta; \theta_D) = \frac{\exp(\beta_0 + \beta_1 x_i + \lambda_d \eta_{i;})}{1 + \exp(\beta_0 + \beta_1 x_i + \lambda_d \eta_{i;})}$$

where θ_D are the parameters of the model for the employment share.

The conditional likelihood of an establishment's employment share of the discriminator occupation is distributed binomial in this probability;

6) $$L_i = \left(\frac{\exp(\beta_{0d} + \beta_{1d}' x_i + \lambda_d \eta_i)}{1 + \exp(\beta_{0d} + \beta_{1d}' x_i + \lambda_d \eta_i)} \right)^d \left(1 - \frac{\exp(\beta_{0d} + \beta_{1d}' x_i + \lambda_d \eta_i)}{1 + \exp(\beta_{0d} + \beta_{1d}' x_i + \lambda_d \eta_i)} \right)^{ste-d} \begin{bmatrix} ste \\ d \end{bmatrix}$$

where ste indexes total establishment employment.[20] [21]

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[20] See Hedeker (2003, p.1439) and Bhat and Gossen (2004 , p.23) There exist a number of ways to motivate the underlying latent variable formulation in 5). In the baseline category model, the formulation is a model of the difference between two iid extreme value distributions, log(P_1) and log(1-P_1), which has a standard logistic distribution. The underlying latent variable approach puts the latent variable on the same scale as the linear predictor, allowing for the direct interpretation of the parameter λ_d as the change in $d*$ per unit change in the latent variable, and facilitating calculation of the share of variance explained by the latent variable model. for discussion.

4.1.4 Accounting for Structural Missingness in the Employment Share of the Discriminator Occupation

Two sets of analyses each contain a certain percentage of establishments that have zero employment of the discriminator occupation. Unbiased estimation of the relationship between the wage measures and the employment share of the discriminator occupation requires that information is captured about the behavior of the wage measures for the group that has zero employment of this occupation.

The zero-inflated binomial model divides the likelihood into separate components for the zero and non-zero units. The likelihood contribution of units for which the employment share is greater than zero is the product of the probability that the employment share is greater than zero and the value of the binomial likelihood when the employment share is greater than zero, while the likelihood contribution of units for which the employment share is zero is the product of the probability that the employment share is zero and the value of the binomial likelihood when the employment share is zero[22];

Let

$$P_0 = P(d = 0) = \frac{\exp(a_1)}{1 + \exp(a_1)}$$

$$P_1 = P(d_i \mid \eta_; ; \theta_D) = \frac{\exp(\beta_0 + \beta_1 x_i + \lambda_d \eta_{i;})}{1 + \exp(\beta_0 + \beta_1 x_i + \lambda_d \eta_{i;})}$$

For observations that have zero employment of the discriminator occupation, we replace 6) with ;

6') $L_i = (P_0)(1 - P_1)^{ste}$

For observations that have positive employment of the discriminator occupation, 6) becomes;

$$L_i = (1 - P_0)(P_1)^d (1 - P_1)^{ste-d} \begin{bmatrix} ste \\ d \end{bmatrix}$$

where (suppressing i subscripts)
d = number of machinists
ste = total establishment employment

[21] McFadden and Train (2000) demonstrated that the mixed logit can be used to attain any desired degree of model fit. This is not true in the current application, because the random intercept can be refuted by a lack of shared variance between the employment share variable and the other measurement items, and the consequent failure to explain a significant portion of the variance of one or more of the other measurement items.

[22] See Hall (2000)

4.1.5 Identification

As in traditional SEM, the model is identified if the number of variances and covariances among the variables exceeds the number of estimated parameters, implying that the degrees of freedom equal the quantity;

$$df = \left(\frac{p(p+1)}{2} - pq - p + \frac{q(q+1)}{2} \right)$$

where
p = number of variables
q = number of factor loadings

The model was identified by restricting several of the parameters. The factor loading on one of the continuous wage variables was set to 1, effectively fixing the scale of the latent variable to the variance of that variable. The mean of the latent variable distribution was set to zero, saving another degree of freedom. Finally, the fixed effects portion of the logit model was moved into an offset term.

4.2 Data and Variables

The precision metal manufacturing sector is currently enjoying something of a comeback in the U.S., where a long history of industry-specific regulation and quality standards accounts for employment systems that continue to be strongly geared toward efforts to maximize quality and productivity.[23] This sector was chosen for the study in the expectation that clear patterns might emerge.

The analyses use data obtained from units in two precision metal manufacturing industries, including mid-sized establishments in the Aircraft Parts (non-engine) Manufacturing sector and large establishments in the Medical Device Manufacturing sector. The analyses of mid-sized establishments in the Aircraft Parts Manufacturing industry use the $wagestruc^p$ WOBO that is designed to covary with the degree of firms' use of a pay-for-performance policy. The analyses of large establishments in the Medical Device Manufacturing sector use the Kremer-Maskin segregation index as the $wagestruc^p$. The KM index and the variable WOBO are defined in detail later in this section.

All of the wage measures are produced using OES data from the May 2009 Survey that are pre-adjusted for the effect of the local area on wage levels. A linear mixed model is used to estimate the Empirical Best Linear Unbiased Predictor (EBLUP) of the random effect of local areas on wages, and this effect is partialed out of each establishment/occupation observation. [*A revision currently in the works replaces this residual with one that is identical to this one, except that the EBLUP of the area wage effect is estimated in a model that accounts for the correlation of wages within both areas and establishments. In the new*

[23] See Arnold, Chris (2011)

model, this residual has partialed out the effect of area, but retains the estimated EBLUP of the establishment wage effect.]

Analysis 1 – Aircraft Parts Manufacturing

The data for each midsize establishment in the Aircraft (non-engine) Parts Manufacturing sector include the wagestruc[p] measure WOBO, defined below, the establishment employment share of machinists, and the establishment average wages of Inspectors and of Team Assemblers.

4.2.1 The wage measures: WOBO, measures of occupational wages, and the establishment wage differential

WOBO

WOBO is the ratio of the average within-occupation wage variance in the establishment to the total wage variance within the establishment, for the group of occupations including production workers and their direct supervisors only. WOBO should be higher in establishments that make greater use of pay for performance policies, because such policies tie wages to actual performance measures rather than to occupational categories.

WOBO is also higher for establishments that have lower between-occupation wage variance for a given level of within-occupation wage variance. Thus, for example, WOBO is higher in establishments that have a smaller wage differential between the wages of production workers and their supervisors, as tends to be the case in establishments in which mobility paths to supervisor status are traversed mainly by former production workers rather than by administrative personnel. WOBO thus combines into a single measure a gauge of establishments' usage of policies associated with pay for performance and wage compression.

The OES data are collected in 12 intervals, rather than as exact wage rates. For this reason, the within-occupation wage variance for a given occupation /establishment is measured as the variance of the 'midpoints' of the OES wage intervals, where each midpoint is weighted by the number of workers in the corresponding earnings interval. The average within-occupation wage variance of an establishment is measured as the average, across occupations in the group including production workers and their supervisors, of the within-occupation wage variances for each occupation, where the weights are the number of workers in each occupation.

The intervalized nature of the OES wage data creates the need to carefully examine this variable to ensure that its calculation using the OES data yields results similar to those that use point (actual wage rate) wage data. This exercise was conducted using point data from the Bureau of Labor Statistics' National Compensation Survey. The correlation between OES-equivalent measures produced using the NCS data and the NCS point data is .97.

Measures of occupational wages

Those occupational wages that are most highly correlated with both the average wage differential of the establishment and the measure WOBO are also important variables, due to the information they carry about the nature of the establishment wage differential. In midsize Aircraft Parts (non-engine) Manufacturing (Naics 336413) establishments, these include Team Assemblers and Inspectors.

The Establishment Wage Differential

The establishment wage differential is constructed as a fixed weight average deviation of the average wage of each occupation in the establishment from its average in the industry/size cell, where the weight for each occupation is its average employment share in the industry/size cell.

4.2.2 The Employment Share of 'Discriminator' Occupations

The 'discriminator' occupations were identified using canonical discriminant analyses in which each multivariate observation contained the employment shares of the largest occupations that together account for eighty percent of average industry employment, and establishments were classified as high wage or low wage on the basis of the average wage differential of the establishment relative to the median wage differential for the industry/size cell.[24] The analyses were conducted by detailed industry/size cell. Among the main discriminator occupations for midsize establishments in Aircraft Parts Manufacturing were Machinists.

Analysis 2 – Medical Device Manufacturing

The data for each large establishment in the Medical Device Manufacturing sector included the Kremer-Maskin segregation index, the establishment employment share of Biomedical Engineers, the establishment average wage of Inspectors, and the establishment wage differential.

4.2.3 The wage measures: the Kremer-Maskin Segregation Index, measures of occupational wages, the establishment wage differential

The analyses use industry/ occupation as a proxy for worker knowledge /skills /abilities.[25] Accordingly, the Kremer-Maskin segregation index, as used here, is a gauge of the degree to which the establishment pays all occupations a uniform differential above or below the market wage for the occupation in the industry/size cell. The KM index equals 1 in an establishment that pays each worker a wage rate that is a fixed percentage above or below the market average wage for her occupation in the industry/size cell. The Kremer-Maskin segregation index for each establishment is ;

$$KM = \frac{\sum_{occs} WT*OD*EWD}{\sum_{occs} WT*OD*OD}$$

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[24] An isometric transformation of the employment shares was used, consistent with the precepts of Composition Analysis.

[25] Groshen (1991) found that occupation /establishment together account for up to 90% of wage variance among production workers.

where
WT is the number of workers in a given Establishment/Occupation cell
OD is the establishment wage differential for a given occupation
EWD is the establishment wage differential

Measures of occupational wages
In the group of large Medical Device sector establishments, those occupational wages that are most highly correlated with both the average wage differential of the establishment and the Kremer-Maskin segregation index are the wages of Inspectors.

4.2.4 The Employment Share of 'Discriminator' Occupations

A main discriminator occupation for the group of large Medical Device sector establishments is Biomedical Engineers.

4.3 Analyses of midsize Aircraft Parts Manufacturers and large Medical Device Manufacturers

The analysis (A1) of midsize Aircraft Parts Manufacturing establishments used a zero inflated binomial model to deal with structural missing-ness in the employment share of the discriminator occupation (Machinists), and otherwise allowed each of the occupational wage variables to be missing.[26]

Three analyses were conducted for the group of large Medical Device sector manufacturers. The first analysis (M1) was similar to the analysis (A1) for Aircraft Parts Manufacturers. This analysis used a zero inflated binomial model to deal with structural missing-ness in the employment share of Biomedical Engineers and otherwise allowed each of the wage variables to be missing.

A second analysis (M2) for this group is identical to (M1), with the exception that, in those establishments that do not employ Biomedical Engineers, the latent variable is defined by the shared variance of the wage measurement items alone. That is, for those establishments that do not employ Biomedical Engineers, 6') is replaced with;

6'') $L_i = (P_0)(1 - P_2)^{ste}$

where

[26]An additional analysis (A2) used an inclusion rule contrived to show the strongest relationships in the data. This analysis appears in the appendix. That analysis used a zero-inflated binomial model to handle structural missing-ness in the employment share of the discriminator occupation, while all occupational wage variables were required to be non-missing.

$$P_0 = P(d=0) = \frac{\exp(a_1)}{1+\exp(a_1)}$$

$$P_2 = P(d_i \mid \eta_i; \theta_D) = \frac{\exp(\beta_0 + \beta_1 x_i)}{1+\exp(\beta_0 + \beta_1 x_i)}$$

For observations that have positive employment of Biomedical Engineers, the previous expressions are unchanged;

$$L_i = (1-P_0)(P_1)^d (1-P_1)^{ste-d} \left[{ste \atop d}\right]$$

Analysis (M2) may reflect more realistic assumptions than (M1), by accounting for structural differences between establishments that do and do not employ Biomedical Engineers.

A third analysis (M3), contained in the Appendix, included only those establishments that employ the discriminator occupation (Biomedical Engineers), and otherwise allowed the occupational wage variables to be missing. This analysis is likely to be biased and was conducted for purposes of comparison with analysis M2 only.

In both sets of analyses, weighting was simplified in an effort to get the analyses to run smoothly. Rather than weight each establishment/occupation observation by the number of employees contributing to the cell, the establishment/occupation observations were instead weighted to equalize the average magnitude of each occupation's contribution to the estimate. For the analysis of midsize Aircraft Parts Manufacturers, the establishment average wages of Inspectors and Team Assemblers entered the analysis unweighted, while the employment share of Machinists was down-weighted to one tenth of its value otherwise. A similar adjustment was made in the analyses of the large Medical Device manufacturers, where the employment share of Biomedical Engineers was down-weighted to eighty percent of its value otherwise. These adjustments prevented the employment share of Machinists /Biomedical Engineers variable from dominating the latent variable.

5. Estimation

The assumption that all measurement items are conditionally independent implies that the conditional likelihood function is the simple Cartesian Product of the conditional likelihood of each variable. The unconditional, or marginal likelihood, is the integral of this likelihood, weighted by the prior density of the random effects.[27]

$$p_i = \int L_i(\theta_d, \theta_j, \eta) f(\eta \mid \phi) d\eta$$

This integral is intractable and in practice we must either approximate the integrand before integrating over the random effects distribution or approximate the integral. Gauss-

[27] See discussion in Hedeker (2003).

Hermite quadrature approximates the integral by a weighted sum of nodes, or quadrature points, that are the roots of a Hermite polynomial. Pinhero and Bates (1995) discuss a variety of methods of approximation techniques including Gaussian Quadrature, and is a primary reference for SAS Proc Nlmixed. Optimization of the approximated likelihood used the quasi-Newton algorithm.

5.1 Evaluating Model Fit

5.1.1 Correlation Residuals

Sources of lack of model fit can sometimes be inferred from the differences between the actual and model-implied correlations of the variables. The difference between them, termed the 'correlation residuals', should be less than .1 in a well-fitting model. The model correlations are given by the first term on the right hand side of Equation 2.

5.1.2 Explained Variance

The share of the variance of each variable that is explained by the latent variable model is derived from the estimated measurement errors together with the simple variance of each variable. For each of the continuous variables y_j, the portion of variance explained by the model follows from the variance expression in 2);

$$R_j^2 = 1 - \frac{\psi_j}{Var(y_j)}$$

Bhat and Gossen (2004) and Snijders and Bosker (1999) discuss calculation of the R-squared value of the mixed logit. The total variance of the employment share is the sum of the fixed, residual, and latent variable contributions to the variance. The residual variance is fixed by assumption to $\frac{\pi^2}{3}$ and the model variance is $\lambda_d^2\phi$. As described in Snijders and Bosker (1999), we must calculate the variance of the fixed portion of the linear predictor using the data. The share of variance explained by the latent variable model is;

$$R_j^2 = \frac{\lambda_d^2\phi}{\lambda_d^2\phi + \mathrm{var}(\mathit{fixed}) + \frac{\pi^2}{3}}$$

5.2 Verifying the Solution

McCullough and Vinod (2003) warn that nonlinear solvers such as Proc Nlmixed provide solutions that are incorrect under a number of conditions that are not automatically detected by the software and that must be carefully examined.

The eigenvalues of the Hessian are a measure of the amount of curvature of the parameter space in the direction of each parameter; small eigenvalues are associated with parameters for which the parameter space is flatter and standard errors are larger, while large eigenvalues are associated with parameters that are more precisely estimated. The solution is a minimum if all eigenvalues are positive, indicating that the Hessian is positive definite.

The condition number of the Hessian, the ratio of the largest to the smallest eigenvalue, is an important indicator of ill-conditioning of the data and high multicollinearity. According to McCullough and Vinod, the condition number of the Hessian in the case of a nonlinear solver should be under 6.7E7.[28]

Coull and Agresti (2000) suggest checking the stability of a solution by inspecting the parameter estimates as a function of the number of quadrature points. A stable solution is indicated when further increases in the number of quadrature points has no effect on the parameter estimates.

6. Results

6.1 Aircraft Parts Manufacturing

Appendix Table A1 contains Pearson correlations, by size groupings, between each of the wage structure measures previously discussed and the occupational wages that are most highly correlated with them. The measures of the establishment wage structure include 1) the average wage differential of the establishment, 2) WOBO, 3) the Kremer-Maskin segregation index (KM), 4) a measure of the within-occupation wage variance in the establishment (VO), which is also the numerator of WOBO, and 5) a measure of the between-occupation wage variance in the establishment (VE).

In the smallest establishments in Aircraft Parts Manufacturing (size 2 and 3), occupations whose wages are most highly correlated with the wage measures include Machinists, Production Worker Supervisors, General Operations Managers, and a range of clerks. In mid-sized establishments (sizes 4 and 5), the list is dominated by Machinists, Inspectors, a range of skilled metal workers, Team Assemblers, and a range of Clerks. In the largest establishments (sizes 6 and 7) the list for size 4 and 5 establishments is expanded to include a range of engineering-related occupations.

In mid-size establishments in Aircraft Parts Manufacturing, those occupational wages that are most highly correlated with the establishment wage differential are the same occupations for which wages are most highly (positively) correlated with the variable WOBO.

In the largest establishments, these same occupations are negatively correlated with WOBO and positively correlated with the Kremer-Maskin Segregation index.
In these establishments, the occupational wages that are most highly correlated with the

[28] Excessive multicollinearity is also indicated by large off-diagonal elements of the correlation matrix of the parameter estimates.

establishment wage differential are the same occupations for which wages are most highly (positively) correlated with the Kremer-Maskin segregation index, KM.

Tables 1_A1 and 1_A1_large contain Pearson correlations between the model variables for midsize and large Aircraft Parts manufacturers. These analyses were designed to be as similar as possible to the full latent variable analysis, by setting the log of the employment share of the discriminator occupation to -11 in the case of zero employment of this occupation, and by allowing each of the occupational wage variables to be missing.

The analyses for both midsize and large Aircraft Parts manufacturers suggest positive correlation between the wages of Inspectors and the employment share of Machinists, and both suggest positive correlation between the wages of Inspectors and the wagestruc ^{p} (WOBO for midsize establishments, the Kremer-Maskin Segregation index for the group of large establishments), and both suggest positive correlation between the wages of Team Assemblers and the wagestruc ^{p}. In the midsize establishments, the employment share of Machinists is positively correlated with the variable WOBO.

Table 2_A1 contains the parameter estimates from the latent variable model discussed in Section 4, applied to the full set of midsize Aircraft Parts Manufacturing establishments. The un-standardized estimates reflect the widely differing scales of the wage versus employment share variables.

Table 3_A1 shows that the latent variable explains about five percent of the variance of establishment wage levels in the Industry/size cell, as well as twenty-five percent of the variance among establishments in the employment intensity of Machinists, nineteen percent of the variance of the wages of Inspectors, fifty-four percent of the variance of Assemblers' wages, and forty percent of the variance of the wagestruc^{p} WOBO.

Tables 4_A1 and 5_A1, respectively, present the juxtaposition of the model correlations with the actual correlations in the data, and the correlation residuals. Table 5_A1 shows that the model over-estimates the correlation between the wage variables and the employment share of Machinists. The correlation residuals associated with several pairs of variables are over .1, suggesting the importance of correlated unmeasured variables that have not been taken into account.[29]

An eigen-analysis of the Hessian shows that the ratio of the largest to smallest eigenvalue is on the order of 10^4.[30]

Correlation analyses for the midsize Aircraft Parts manufacturers suggest that there exists especially strong shared variance among the measurement items in the thirty three establishments that employ both Inspectors and Team Assemblers. While the constraints of model identification preclude the ability to formally test for structural differences between the establishments that do and do not employ both of these occupations, an

[29] See discussion in Kline (1998) p.20-22.
[30] Appendix Figure A1 contains histograms of the actual and predicted values of the employment share of Machinists, and of the predicted value of the latent variable.

auxiliary analysis of the latent variable model was conducted using these thirty three establishments. The analysis is otherwise identical to analysis A1.

The results of this analysis, contained in Appendix Tables 1_A2-5_A2, are probably biased. Appendix Table 1_A2 contains Pearson correlations between the model variables for midsize and large Aircraft Parts manufacturers, and Appendix Table 1_A2_alpha shows the results of using SAS proc CORR to produce Cronbach's Alpha index of reliability, which measures the average correlation of the variables, on this group of establishments. Observations for establishments that did not employ Machinists were handled by assigning the log employment share of Machinists a value of -11.

The analysis of the latent variable model is otherwise identical to analysis A1. The results show that the latent variable explains about forty-seven percent of the variance of the employment intensity of Machinists, thirty-two percent of the variance of the wages of Inspectors, fifty-two percent of the variance of Assemblers' wages, and sixty-eight percent of the variance of the wagestruc[p] WOBO. Auxiliary calculations suggest that the latent variable also explains about 27% of the variance of establishment wage levels in this group.

Tables 4_A2 and 5_A2 suggest a similar degree of model fit to the earlier analysis.

6.2 Medical Device Manufacturing

Appendix Table B1 contains Pearson correlations, by size groupings, between each of the wage structure measures and the occupational wages that are most highly correlated with them. The table contains measures of the wage structure including ; 1) the average wage differential of the establishment, 2) WOBO, 3) the Kremer-Maskin segregation index (KM), 4) a measure of the within-occupation wage variance in the establishment (VO), which is also the numerator of WOBO, and 5) a measure of the between-occupation wage variance in the establishment (VE). The table shows that, in all size establishments in this sector, occupations whose wages are most highly correlated with measures of the establishment wage structure include Assemblers, Inspectors, Production Supervisors, Laboratory Technicians, and Machinists.

Tables 1_M1 – 5_M1 contain the results of analysis (M1) discussed in Section 4.3. This analysis used the full set of large Medical Device Sector establishments, and is parallel to that shown in Table 1_A1 for Aircraft Parts; the log of the employment share of Biomedical Engineers is set to -11 in the case of zero employment of this occupation, and each of the occupational wage variables are allowed to be missing. The establishment wage differential is highly correlated with both the Kremer-Maskin segregation index and the wages of Inspectors, and the Kremer-Maskin segregation index is highly correlated with the wages of Inspectors. None of the variables are correlated with the employment share of Biomedical Engineers.

Tables 2_M1 - 5_M1 show the results of the latent variable model analysis for this group. This analysis used the zero inflated binomial model for the employment share of Biomedical Engineers and otherwise allowed all wage variables to be missing. The results for this model show that it has no power to explain the pattern by which some establishments employ Biomedical Engineers and others do not. While the wages of Inspectors and the average wage level of the establishment share a considerable amount of variance with the Kremer-Maskin segregation index, the employment share of Biomedical Engineers shares almost none.

Table 2_M2 contains the parameter estimates from the analysis of model (M2) discussed in Section 4.3. This analysis is exactly like model (M1), except the case of non-employment of Biomedical Engineers is assumed to be unrelated to the latent variable. In other words, non-employment of Biomedical Engineers is not assumed to be correlated with smaller values of the latent variable. Instead, we assume the two groups are structurally different; the focus of these establishments' activities is elsewhere and unknown, although they share with the other group of establishments strong relationships underlying the wage structure of the establishment, between the average level of wages in the establishment, the Kremer-Maskin Segregation Index, and the wages of Inspectors.

This assumption is implemented as a single zero parameter restriction on the factor loading in the logit model for the establishments that do not employ Biomedical Engineers. The Likelihood Ratio Test comparing this model with the full M1 model confirms that the restricted model is a vast improvement.

Table 3_M2 contains R Squared measures for this model. The latent policy effect explains over ninety percent of the variance of establishments' wage levels in this group, as well as thirty percent of the variance in the employment intensity of Biomedical Engineers, forty-nine percent of the variance in the wages of Inspectors, and seventy-seven percent of the variance among establishments in the Kremer-Maskin segregation index.

Tables 4_M2 and 5_M2, respectively, present the juxtaposition of the model correlations with the actual correlations in the data, and the correlation residuals. Several of the correlation residuals in Table 5_M2 exceed .1 in magnitude, suggesting the importance of correlated unmeasured variables that have not been taken into account.

An eigen-analysis of the Hessian shows that the ratio of the largest to smallest eigenvalue is on the order of $6.2E^{6}$.

Appendix Table 1_M3 contains Pearson Correlations between the variables in analysis (M3), discussed in Section 4.3. This analysis restricts the data to those establishments that employ Biomedical Engineers and is likely to be biased. In this group, the establishment wage differential is highly correlated with both the Kremer-Maskin segregation index and the wages of Inspectors, and the Kremer-Maskin segregation index is highly correlated with the wages of Inspectors. The establishment wage differential and the KM index exhibit similar correlation with the employment share of Biomedical Engineers (about .3). The correlation between the wages of Inspectors and the employment share of Biomedical Engineers is about .54.[31]

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[31] Appendix Table 1_M3_alpha reports the results of analyses using SAS Proc CORR to produce Cronbach's Alpha index of reliability using the set of establishments restricted to include only those

Appendix Table 2_M3 contains the parameter estimates from the latent variable model applied to this group.

Appendix Table 3_M3 contains R Squared measures. The latent policy effect explains about seventy percent of the variance of establishments' wage levels in this group, as well as thirty-four percent of the variance in the employment intensity of Biomedical Engineers, forty-nine percent of the variance in the wages of Inspectors, and thirty-five percent of the variance among establishments in the Kremer-Maskin segregation index.

Appendix Tables 4_M3 and 5_M3, respectively, present the juxtaposition of the model correlations with the actual correlations in the data, and the correlation residuals. Appendix Table 5_M3 shows that the model significantly under-estimates the correlation between the KM index and both the establishment wage differential and the wages of Inspectors, as well as the correlation between the wages of Inspectors and the establishment wage differential, while it over-estimates the correlation between the employment share of Biomedical Engineers and the other variables. Several of the correlation residuals in Appendix Table 5_M3 exceed .1 in magnitude, suggesting the importance of correlated unmeasured variables that have not been taken into account. An eigen-analysis of the Hessian shows that the ratio of the largest to smallest eigenvalue is on the order of $3.2E^{7}$.

7. Discussion

The latent variable analyses provide information about the likely causal factors driving the wage structure of establishments in each of the two sectors. In the group of midsize Aircraft Parts manufacturing establishments, the analyses suggest that the wages and employment intensities of certain key occupations are codetermined alongside policies that increase wage variance within occupations. Specifically, in this group of establishments, the results suggest that policies that increase within-occupation wage variance are both an increasing function of the degree of technicality of the production process, as gauged by the employment intensity of Machinists, and are targeted to the Inspector and Assembler occupational groups. The results are consistent with the possibility that establishments' usage of pay-for-performance policies underlie these patterns.

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that employ each of the occupations included in the analysis. The results show slightly higher correlation between the KM index and the employment share of Biomedical Engineers than between the establishment wage differential and the employment share of Biomedical Engineers. If confirmed in other studies, these results could suggest that correlation between the employment share of Biomedical Engineers and the establishment wage differential works through the effects of worker sorting on the wage structure of establishments in this sector. They suggest that increased complexity of the production process, as proxied by larger employment shares of Biomedical Engineers, is associated with both higher establishment wage differentials and higher indices of worker sorting.

Other studies have found that measures of pay-for-performance are not highly predictive of the establishment wage level, and this pattern is also found here. The latent variable explains only about five percent of the variance of establishment wage levels in this group, although it explains a considerable share of the variance of wages or employment of each of the detailed occupations with which it is most highly correlated.

In the group of large Medical Device manufacturing establishments, the analyses suggest that the wages and employment intensities of certain key occupations are codetermined alongside policies that increase the degree of worker sorting in the establishment. More specifically, in this group of establishments, the results suggest that the degree to which workers in the establishment are sorted into similar skill levels is both an increasing function of the degree of technicality of the production process, as gauged by the employment intensity of Biomedical Engineers, and is disproportionately targeted to Inspectors.

The analysis of large Medical Device manufacturers offers an interpretation of the results of Osburn (2000), which found that the occupational wages most highly correlated with the all-occupation mean wage differential of detailed manufacturing industries are those occupations most directly involved in the primary activities of the organization, and those most directly involved in the most technical and complex activities. These include occupations involved in coordination functions, skilled production work, and quality control. Since those analyses did not control for establishment size, the results were dominated by the effects of large establishments.

Those results (Osburn, 2000) showed that the wages of Inspectors were among the most highly correlated with the all-occupation mean wage differential of detailed manufacturing industries, along with the wages of Industrial Production Managers, Personnel, Training, and Labor Relations Specialists, and Supervisors of Operators. The results of the current analyses of large Medical Device manufacturers are consistent with the notion that, in the group of establishments studied, high correlation between the wages of Inspectors and the *establishment* wage differential is but one of the outcomes generated as establishments attempt to compete. The larger picture is one in which the wages/skill levels of Inspectors also exhibit strong positive correlation with both the degree of technical complexity of the production process and the degree to which the skills levels of all workers in the establishment are similar, relative to others in their given occupation. This pattern certainly suggests a production function similar to that described by Kremer and Maskin (1993, 1996). Moreover, this pattern explains about half of the variance of establishment wage levels in this group.

The high degree of industry and occupational detail of the OES data also allows examination of relationships similar those discussed by Lazear /Shaw (2008). As discussed in Section 3, Lazear and Shaw examined a range of countries and found that, in all of them, measures of firm-level wage differentials are correlated with measures of within-firm wage variance, and within-firm wage variance in fact accounts for between 60 and 80 percent of total wage variance. Measures similar to those produced by Lazear and Shaw are here produced at the establishment level, rather than at the firm level, and for detailed industry

/size cells, rather than for entire countries.

Tables 1_A1 (midsized establishments) and 1_A1_large (large establishments, see file Tables 1_5_A1) contain correlations between a variety of variables related to the analysis of Aircraft Parts manufacturers. Table 1_A1 tells a story for mid-sized Aircraft Parts manufacturers that is similar to that of Lazear and Shaw (2008), but provides additional information made possible by the disaggregation of within establishment wage variance into within-occupation and between-occupation (not shown in the table) components. The table shows that the (albeit low, .33) correlation between establishment wage differentials (Estabdiff) and within-establishment wage variance (Var_Estab) primarily reflects correlation between establishment wage differentials and within-establishment /within-occupation (Var_Occ) wage variance (.23). These results are consistent with the notion, discussed in Lazear and Shaw (2008), that correlation between firm-level wage differentials and within-firm wage variance may reflect correlation between firms' wage levels and their usage of wage policies such as pay for performance. Previous studies have often used yes/no indicators of such usage, and it is quite possible that the simple existence of such a policy does not tell one much about what is going on in the establishment. The current study used a measure of within-occupation wage variance that may or may not be highly correlated with the *intensity* with which pay for performance policies are used in the establishment.

8. Conclusions and Directions for Future Study

Future work will identify relatively homogeneous sub-groups of establishments in each of the industry/size cells studied, for the purpose of gaining a deeper understanding of the differences in the occupational staffing patterns between establishments having a higher or lower score on the latent variable.

Future work will also take a wider look at similar relationships in other sectors as well as re-examine the industries studied here using OES establishment-level data that is linked by firm. The latter is in accordance with findings of Pil and Macduffie (1996) that, while plant-level characteristics are predictive of the use of high-involvement work practices, company-level characteristics are even more so. These data will be used to examine the degree to which inter-firm wage differentials are explained by intra-firm measures of the wage structure such as those examined in this paper. Future work will also bring in firm-level performance measures where possible, to examine the relationships between measures of the firm wage structure, organizational performance, and the wages and employment intensities of detailed occupations.

Any opinions expressed in this paper are those of the author and do not constitute policy of the Bureau of Labor Statistics

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Appendix A1. Pearson Correlations - Wages of Detailed Occupations /
Five Measures of the Establishment Wage Structure
Aircraft Parts Manufacturing (non-engine)

1. ed Establishment Wage Differential
2. wb WOBO (Within Occupation Wage Variance Relative to Between Occ Wage Var.)
3. km Kremer-Maskin Segregation Index
4. vo Within-Occupation Wage Variance (Numerator of WOBO)
5. ve Between-Occupation Wage Variance (Denominator of WOBO)

Establishment size	Occupation Title	Wage Stucture Measure	Corr	p	N
2	Machinist	ed	0.96	0.000	32
	Prd_supervisor		0.67	0.001	22
2	Prd_supervisor	ve	0.85	0.000	22
	Machinist		0.33	0.122	23
	Machinist		0.89	0.000	32
	Gen_Op_mgr		0.64	0.000	37
3	Secretary	ed	0.54	0.005	25
	Prd_supervisor		0.49	0.001	44
	Office_clk		0.44	0.045	21
	Machinist		-0.88	0.000	24
3	Gen_Op_mgr	km	-0.58	0.002	25
	Prd_supervisor		-0.42	0.017	31
	Prd_supervisor		-0.50	0.004	31
3	Machinist	wb	0.17	0.440	24
	Gen_Op_mgr		-0.03	0.890	25
	Prd_supervisor		0.59	0.000	44
	Office_clk		-0.56	0.008	21
3	Secretary	ve	-0.27	0.213	23
	Gen_Op_mgr		0.16	0.357	35
	Machinist		-0.10	0.599	31
	Machinist		0.53	0.008	24
3	Prd_supervisor	vo	0.27	0.149	31
	Gen_Op_mgr		0.23	0.263	25
	Machinist		0.77	0.000	44
	Welder		0.68	0.001	21
4	Mill machine	ed	0.67	0.000	46
	Inspector		0.64	0.000	59
	Misc Prd		0.64	0.001	23
	Production Plan Clerk		0.43	0.009	36
	Team Assembler		0.40	0.047	25
	Machinist		-0.78	0.000	43
4	Inspector	km	-0.64	0.000	58
	Mill_mach		-0.58	0.000	44
	Gen_Op_mgr		-0.57	0.000	66

Establishment size	Occupation Title	Wage Stucture Measure	Corr	p	N
4	Prd_supervisor	km	-0.54	0.000	71
	Tm Assembl		0.52	0.007	25
	Welder		0.49	0.023	21
4	Bkkp, Act Clks	wb	0.39	0.012	41
	Mill_mach		0.38	0.012	44
	Ship_clerk		0.35	0.006	60
	Inspector		0.24	0.074	58
	Prd_super		0.52	0.000	71
	Office_clk		0.39	0.012	41
4	Misc Prd	ve	0.38	0.075	23
	Prdpln_clk		0.37	0.031	35
	Mill_mach		0.68	0.000	44
	Inspector		0.46	0.000	58
	Welder		0.46	0.037	21
	Misc Prd		0.43	0.039	23
4	Sales_Rep	vo	0.33	0.046	38
	Admin_supr		0.33	0.104	26
	Prd_supervisor		0.31	0.008	71
	Tm Assembl		0.30	0.141	25
	Tm Assembl		0.84	0.000	24
	Tool_n_Die		0.70	0.000	23
	Machinist		0.69	0.000	31
5	Inspector	ed	0.68	0.000	52
	Stock_clrk		0.64	0.000	28
	Janitor		0.64	0.001	24
	Fin Managr		-0.31	0.141	24
	Tool_n_Die		-0.30	0.168	23
	Hlth & Safety Eng.		-0.27	0.191	25
5	Prd_super	km	-0.26	0.060	55
	Sales_Rep		-0.24	0.165	34
	Machinist		-0.22	0.240	31
	Tm Assembl		0.54	0.008	23
	Admin_supr		0.46	0.015	27
5	Office_clk	wb	0.45	0.007	35
	Inspector		0.45	0.001	51
	Janitor		0.41	0.054	23
	Inspector		0.32	0.019	52

Establishment size	Occupation Title	Wage Stucture Measure	Corr	p	N
	Hlth & Safety Eng.		-0.28	0.171	26
	Prd_super		0.26	0.055	57
5	Tool_n_Die	ve	0.24	0.266	23
	Chief_Exec		-0.21	0.229	34
	Office_clk		0.17	0.322	35
	Machinist		0.15	0.433	31
	Inspector		0.59	0.000	51
	Janitor		0.46	0.026	23
	Tm Assembl		0.43	0.039	23
	Office_clk		0.43	0.010	35
5	Enginr_mgr	vo	0.40	0.039	27
	Tool_n_Die		0.37	0.078	23
	Chief_Exec		-0.26	0.159	32
	Aerosp_Eng		0.82	0.000	33
	Machinist		0.75	0.000	52
6	Inspector	ed	0.73	0.000	66
	Drafters		0.70	0.000	32
	Cmptr_cntP		0.69	0.000	32
	Mill_mach		0.66	0.000	44
	Painting		0.63	0.001	23
	ArcftAssem		0.62	0.002	22
	Aerosp_Eng		0.71	0.000	32
	Inspector		0.59	0.000	65
	Elec. Drafters		0.58	0.000	33
	Payroll Clks		0.58	0.000	33
	Drafters		0.56	0.001	32
6	Machinist	km	0.55	0.000	52
	Ship_clerk		0.55	0.000	62
	Mill_mach		0.54	0.000	43
	Prd_super		0.54	0.000	68
	ArcftAssem		0.52	0.013	22
	Tm Assembl		0.51	0.007	27
	Painting		0.39	0.075	22
	Mill_mach		0.35	0.021	43
6	Drafters	wb	-0.35	0.050	32
	Bkkp, Act Clks		0.35	0.011	53
	Tm Assembl		0.33	0.093	27
	Enginr_mgr		-0.33	0.021	49
	Tool_n_Die		0.32	0.115	26
	Painting		0.57	0.005	23

Establishment size	Occupation Title	Wage Stucture Measure	Corr	p	N
	Prd_super		0.50	0.000	69
	ArcftAssem		0.47	0.027	22
	IndPrd_mgr		0.39	0.002	60
6	Inspector	ve	0.36	0.003	66
	Misc Prd		-0.35	0.066	28
	Payroll Clks		0.34	0.050	34
	Tm Assembl		0.34	0.081	28
	Painting		0.71	0.000	22
	Tm Assembl		0.47	0.013	27
	Engineer Tech		0.45	0.009	33
	Tool_n_Die		0.40	0.046	26
6	Welder	vo	0.38	0.090	21
	ArcftAssem		0.36	0.101	22
	IndPrd_mgr		0.34	0.009	59
	Ship_clerk		0.88	0.000	28
	Machinist		0.88	0.000	26
	Inspector		0.87	0.000	34
7	Mill_mach	ed	0.84	0.000	21
	Indus.Mach.Install		0.78	0.000	29
	Stock_clrk		0.70	0.000	23
	Accountants, Aud.		-0.02	0.902	32
	Machinist		0.85	0.000	26
	Ship_clerk		0.73	0.000	27
7	Inspector	km	0.61	0.000	33
	Prd_super		0.60	0.000	34
	Tool_n_Die		0.55	0.005	24
	Drafters		-0.56	0.008	21
	Mech_Eng		-0.47	0.026	22
7	Stock_clrk	wb	0.41	0.057	22
	Sales_Rep		-0.38	0.085	21
	Bkkp, Act Clks		-0.37	0.074	24
	Office_clk		0.29	0.196	21
	Prd_super		0.58	0.000	34
	Tool_n_Die		0.55	0.005	24
	Machinist		0.51	0.008	26
7		ve	0.43	0.052	21
	Prdpln_clk		0.41	0.023	31
	Inspector		0.37	0.029	34
			0.37	0.037	33
	Tool_n_Die		0.45	0.026	24
7		vo	0.43	0.050	21
	Inspector		0.41	0.019	33

Establishment size	Occupation Title	Wage Stucture Measure	Corr	p	N
	Prd_super		0.40	0.021	34
7		vo	-0.37	0.041	31
	Machinist		0.36	0.067	26
	Mill_mach		0.34	0.137	21
	Prdpln_clk		0.30	0.106	30

Appendix B1. Pearson Correlations - Wages of Detailed Occupations /
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Medical Device Sector Establishments

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3. km Kremer-Maskin Segregation Index
4. vo Within-Occupation Wage Variance (Numerator of WOBO)
5. ve Between-Occupation Wage Variance (Denominator of WOBO)

Establishment size	Occupation Title	Wage Stucture Measure	Corr	p	N
2	Prd_supervisor		0.84	0.000	26
2	Medical, Dental, and Opthalmic Lab. Tech	ed	0.81	0.001	13
2	Machinist		0.61	0.045	11
2	Tm Assemblers		0.53	0.021	19
2	Medical, Dental, and Opthalmic Lab. Tech		0.86	0.000	13
2	Prd_supervisor	km	0.76	0.000	26
2	Tm Assembl		0.58	0.009	19
2	Prd_supervisor	ve	0.77	0.000	26
3	Inspector		0.76	0.002	14
3	Prd_supervisor		0.72	0.000	32
3	Sales_Rep	ed	0.56	0.015	18
3	Tm Assembl		0.45	0.040	21
3	Gen_Op_mgr		0.38	0.034	31
3	Inspector		0.77	0.001	14
3	Prd_supervisor	km	0.62	0.000	32
3	Tm Assembl		0.57	0.007	21
3	Gen_Op_mgr		0.44	0.013	31
3	Prd_supervisor	pj	-0.47	0.006	32
3	Prd_supervisor	ve	0.67	0.000	32
4	Tm Assembl		0.84	0.000	44
4	Machinist		0.74	0.000	22
4	IndusEngnr		0.68	0.000	24
4	Medical, Dental, and Opthalmic Lab. Tech		0.67	0.013	13
4	Prd_supervisor		0.65	0.000	60
4	Inspector		0.63	0.000	45
4	Mech_Eng	ed	0.60	0.002	24
4	Prch_agent		0.54	0.003	28
4	Mach__Mech		0.49	0.041	18
4	IndPrd_mgr		0.48	0.001	43
4	Secretary		0.45	0.012	31
4	Fin Managr		0.43	0.034	24
4	Sales_Rep		0.38	0.027	34
4	Bookkeeprs		0.36	0.043	32
4	Tm Assembl	km	0.72	0.000	44
4	Medical, Dental, and Opthalmic Lab. Tech		0.67	0.012	13

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5. ve Between-Occupation Wage Variance (Denominator of WOBO)

Establishment size	Occupation Title	Wage Stucture Measure	Corr	p	N
4	Machinist		0.64	0.001	22
4	Prd_super		0.63	0.000	60
4	Mech_Eng		0.56	0.005	24
4	IndusEngnr		0.55	0.006	24
4	IndPrd_mgr	km	0.54	0.000	43
4	Inspector		0.53	0.000	45
4	Prch_agent		0.41	0.030	28
4	Bookkeeprs		0.41	0.021	32
4	Sales_Rep		0.40	0.020	34
4	Prd_super		0.61	0.000	60
4	Enginr_mgr		0.52	0.018	21
4	Mach__Mech	ve	0.50	0.034	18
4	Machinist		0.44	0.039	22
4	Bookkeeprs		0.40	0.025	32
4	IndPrd_mgr	vo	-0.36	0.017	43
5	Mill_mach		0.81	0.000	14
5	Tm Assembl		0.79	0.000	35
5	Customer Service Rep.		0.77	0.000	24
5	Prd_super	ed	0.74	0.000	48
5	Stock_clrk		0.73	0.008	12
5	Inspector		0.71	0.000	41
5	IndusEngnr		0.70	0.000	34
5	Machinist		0.69	0.001	19
5	Tm Assembl		0.68	0.000	35
5	Machinist		0.62	0.005	19
5	IndusEngnr		0.57	0.000	34
5	Prd_super	km	0.56	0.000	48
5	Fin Managr		0.54	0.005	25
5	Enginr_mgr		0.50	0.029	19
5	Inspector		0.49	0.001	41
5	Admin_supr		0.48	0.016	25
5	Mech_Eng		0.62	0.008	17
5	Employment, Recruit Spclst	pj	0.51	0.038	17
5	Prd_super		-0.35	0.015	48
5	Gen_Op_mgr	pj	-0.36	0.019	42

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Establishment size	Occupation Title	Wage Stucture Measure	Corr	p	N
5	Admin_supr		-0.42	0.035	25
5	Reception		0.76	0.000	18
5	Prd_super		0.63	0.000	48
5	Customer Service Rep.	ve	0.54	0.006	24
5	IndPrd_mgr		0.45	0.004	39
5	Inspector		0.44	0.004	41
5	Bookkeeprs		0.43	0.035	24
5	Reception	vo	0.72	0.001	18
5	Tm Assembl		0.36	0.032	35
6	Tm Assembl		0.83	0.000	49
6	Machinist		0.75	0.000	35
6	Elec Assem		0.75	0.000	22
6	SuperHlprs		0.69	0.003	16
6	Inspector	ed	0.69	0.000	61
6	Forging Machine Setter		0.66	0.029	11
6	Stock_clrk		0.63	0.000	34
6	SuprMechan		0.62	0.001	27
6	Ship_clerk		0.62	0.000	54
6	IndusEngnr		0.61	0.000	62
6	Tm Assembl		0.78	0.000	49
6	Elec Assem		0.77	0.000	22
6	Machinist		0.68	0.000	35
6	Stock_clrk		0.68	0.000	34
6	Misc. Engineers		0.67	0.011	13
6	SuperHlprs	km	0.63	0.010	16
6	IndusEngnr		0.58	0.000	62
6	SuprMechan		0.58	0.002	27
6	Mill_mach		0.58	0.001	28
6	Prch_agent		0.57	0.000	60
6	Ship_clerk		0.57	0.000	54
6	Mill_mach		0.49	0.008	28
6	IndPrd_mgr	pj	-0.28	0.024	63
6	Prd_super		-0.29	0.016	66
6	Survey Researchers	ve	0.46	0.037	21
6	Sales_Rep		0.35	0.015	49

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Establishment size	Occupation Title	Wage Stucture Measure	Corr	p	N
6	Prd_super	ve	0.33	0.007	66
6	Chief_Exec		-0.34	0.035	38
6	Mill_mach		-0.39	0.039	28
6	First Line Supervisor Sales Wkrs		0.48	0.025	22
6	Customer Service Rep.	vo	0.36	0.008	52
6	Drafters		-0.57	0.025	15
6	Electrical Engineers		-0.70	0.004	15
7	Tm Assembl		0.81	0.000	45
7	Inspector		0.74	0.000	51
7	Ship_clerk		0.73	0.000	41
7	Laborers		0.73	0.000	51
7	Molders and Molding Mach. Setters	ed	0.73	0.000	19
7	Human Resource Assistants		0.71	0.001	19
7	Stock_clrk		0.70	0.000	34
7	Packaging and Filling Machine Op.,Tnd.		0.68	0.004	16
7	Elec Assem		0.68	0.000	25
7	Misc. Engineers		0.66	0.029	11
7	Tm Assembl		0.80	0.000	45
7	Inspector		0.72	0.000	51
7	Ship_clerk		0.72	0.000	41
7	Misc. Engineers		0.70	0.016	11
7	Stock_clrk		0.70	0.000	34
7	Laborers		0.70	0.000	51
7	Human Resource Assistants		0.63	0.004	19
7	Molders and Molding Mach. Setters	km	0.61	0.005	19
7	Elec Assem		0.57	0.003	25
7	IndusEngnr		0.56	0.000	53
7	Machinist		0.55	0.002	29
7	SuperHlprs		0.55	0.006	24
7	Packaging and Filling Machine Op.,Tnd.		0.54	0.032	16
7	SuprMechan		0.52	0.000	43
7	Employment, Recruit Spclst		-0.25	0.017	93
7	Enginr_mgr	pj	-0.28	0.039	55
7	Stock_clrk		-0.38	0.028	34
7	Forging Machine Setter	vo	-0.69	0.012	12

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4. vo Within-Occupation Wage Variance (Numerator of WOBO)
5. ve Between-Occupation Wage Variance (Denominator of WOBO)

Establishment size	Occupation Title	Wage Stucture Measure	Corr	p	N

Table 1_A1. Aircraft Parts - Pearson Correlations

rund_blot_r6 - Size 4&5 Estabs, all obs. (log employment share Machinists = -11 where missing)

	Estabdiff	Kremer-Maskin	WOBO	Emp. Share Machinists	Var_Estab	Var_Occ	Wage Inspectors	Wage Assemblers
Estabdiff	—							
Kremer-Maskin								
	0.13	-0.01						
WOBO	0.120	0.950						
	142	142						
Emp.Share	0.04	0.01	0.13					
Machinists	0.580	0.930	0.130					
	150	150	142					
0.030	0.18	-0.22	-0.15	0.17				
Var_Estab		0.007	0.080	0.830				
	147	147	142	147				
	0.31	-0.22	0.28	0.09	0.69			
Var_Occ	0.000	0.008	0.001	0.250	0.000			
	142	142	142	142	142			
Wage	0.61	-0.42	0.32	0.15	0.19	0.51		
Inspectors	0.0001	0.000	0.001	0.120	0.050	0.000		
	111	111	109	111	111	109		
Wage	0.63	-0.26	0.55	0.19	-0.02	0.42	0.54	
Assemblers	0.0001	0.070	0.000	0.180	0.890	0.003	0.001	—
	49	49	48	49	49	48	34	

Table 1_A1_large. Aircraft Parts Manufacturing - Pearson Correlations by Establishment Size

sizes 6&7	Estabdiff	Kremer-Maskin	WOBO	Emp. Share Machinists	Var_Estab	Var_Occ	Wage Inspectors	
Kremer-	0.80							
Maskin	0.000	—						
	108							
	-0.03	-0.07						
WOBO	0.792	0.503	—					
	106	106						
Emp. Share	0.14	0.08	-0.03					
Machinists	0.136	0.427	0.775	—				
	108	108	106					
	0.33	0.32	-0.08	-0.21				
Var_Estab	0.000	0.001	0.389	0.028	—			
	108	108	106	108				
	0.23	0.20	0.40	-0.26	0.79			
Var_Occ	0.016	0.044	0.000	0.007	0.000	—		
	106	106	106	106	106			
Wage	0.72	0.48	-0.03	0.27	0.19	0.10		
Inspectors	0.000	0.000	0.803	0.007	0.065	0.333	—	
	100	100	98	100	100	98		
Wage	0.62	0.40	0.25	0.26	0.06	0.10	0.76	
Assemblers	0.000	0.006	0.105	0.086	0.671	0.510	0.000	—
	46	46	45	46	46	45	42	

Table 2_A1. Aircraft Parts Manufacturing (non-Engine), Size 4 and 5 Establishments

Analysis Rund_blot_r6, All Observations, zero inflated binomial model for employment share

	Parameter Estimates			
Parameter	Unstd.	Std.	SE	Probt
Wage Tm Assemblers	0.5400	0.74	0.1600	0.0007
Wage Inspectors	0.2700	0.43	0.0900	0.0040
WOBO	1.0000	0.63		
Emp Share Machinists	3.2500	0.51	0.9800	0.0012
Variances				
Meas error WOBO	0.1600			0.0001
Meas error Wg Tm Assemblers	0.0250			0.0150
Meas error Wg Inspectors	0.0330			0.0001
Random Effect Establishment	0.3300			0.0001
-2LL = -197.7				
N=452, Subjects = 150				

Table 3_A1. R Squared

Share Machinists	WOBO	Wg Tm Assemblers	Wg Inspectors
0.25	0.40	0.54	0.19

Table 4_A1: Model Correlations and Data Correlations
Size 4 and 5 Establishments
All Observations Rund_blot_r6

Model / Data	Wg Tm Assemblers	Wg Inspectors	WOBO	Share Machinists
Wg Tm		0.54	0.55	0.19
		0.00	0.00	0.18
Assemblers		34	48	49
Wg	0.32		0.32	0.15
			0.00	0.12
Inspectors			109	111
WOBO	0.47	0.27		0.13
				0.13
				142
Share Machinists	0.38	0.22	0.32	

Table 5_A1: Correlation Residuals
Size 4 and 5 Establishments

	Wage Team Assemblers	Wage Inspectors	WOBO	Employment Share Machinists
Wage Team Assemblers				
Wage Inspectors	-0.22			
WOBO	-0.08	-0.05		
Emp. Share Machinists	0.19	0.07	0.19	

Appendix Table 1_A2_alpha. Aircraft Parts Manufacturing - Cronbach Alpha

Counterpart to latent variable analysis rund_blot_r4

Employment share -11 when missing, All wage variables must be present

Size 4 & 5

N=33

Alpha=.75	WOBO	Emp. Share Machinists	Wage Inspectors	Wage Assemblers
WOBO	__			
Emp. Share Machinists	0.36 0.040	__		
Wage Inspectors	0.47 0.006	0.33 0.060	__	
Wage Assemblers	0.60 0.000	0.24 0.180	0.56 0.001	__

Appendix Table 1_A2. Aircraft Parts Manufacturing - Pearson Correlations by Establishment Size

Size 4&5 establishments, emp share of machinists > 0, Wage variables allowed to be missing

	Estabdiff	Kremer-Maskin	WOBO	Emp. Share Machinists	Var_Estab	Var_Occ	Wage Inspectors	Wage Assemblers
Estabdiff	__							
Kremer-Maskin	-0.79 0.0001 75	__						
WOBO	0.16 0.180 74	0.06 0.610 74	__					
Emp.Share Machinists	-0.14 0.240 75	0.28 0.020 75	0.37 0.001 74	__				
Var_Estab	0.12 0.300 75	-0.15 0.210 75	-0.15 0.210 74	0.22 0.060 75	__			
Var_Occ	0.31 0.006 74	-0.18 0.120 74	0.18 0.120 74	0.36 0.002 74	0.89 0.000 74	__		
Wage Inspectors	0.59 0.000 62	-0.36 0.004 62	0.29 0.020 61	0.09 0.480 62	0.24 0.060 62	0.55 0.000 61	__	
Wage Assemblers	0.76 0.000 22	-0.25 0.260 22	0.69 0.000 22	0.29 0.190 22	0.00 0.990 22	0.54 0.009 22	0.55 0.020 18	__

Appendix Table 2_A2. Parameter Estimates				
	Parameter Estimates			
Parameter	Unstd.	Std.	SE	Probt
Wage Tm Assemblers	0.4478	0.72	0.1167	0.0006
Wage Inspectors	0.2808	0.57	0.0959	0.0062
WOBO	1.0000	0.82		
Emp Share Machinists	4.2406	0.68	0.9029	<.0001
Variances				
Meas error WOBO	0.0804		0.0354	0.0297
Meas error Wg Tm Assemblers	0.0305		0.0099	0.0044
Meas error Wg Inspectors	0.0258		0.0073	0.0013
Random Effect Establishment	0.4019		0.0788	<.0001
-2LL = -126.5				
N=132, Subjects = 33				

Appendix Table 3_A2. R Squared Wage Variables and Employment Share Machinists			
Share	WOBO	Wg Tm Assemblers	Wg Inspectors
0.47 (latent variable portion only)	0.68	0.52	0.32

Appendix Table 4_A2: Model Correlations and Data Correlations Size 4 and 5 Establishments Coefficient Alpha-Comparable Analysis N=33				
Data Model	Wg Tm Assemblers	Wg Inspectors	WOBO	Share Machinists
Wg Tm Assemblers	_	0.56 0.001	0.47 0.006	0.33 0.060
Wg Inspectors	0.41	_	0.60 0.0002	0.24 0.180
WOBO	0.58	0.47	_	0.36 0.040
Share Machinists	0.41	0.39	0.56	_

Appendix Table 5_A2. Correlation Residuals Size 4 and 5 Establishments Coefficient Alpha-Comparable Analysis N=33				
	Wage Team Assemblers	Wage Inspectors	WOBO	Employment Share Machinists
Wage Team Assemblers	_			
Wage Inspectors	-0.15	_		
WOBO	0.11	0.13	_	
Employment Share Machinists	0.08	0.15	0.20	_

Table 1_M1. Medical Device Manufacturing - Pearson Correlations

Size 6 & 7 Establishments, all observations (log employment share = -11 when missing)

	Estabdiff	Kremer-Maskin	Emp Share Biomed. Eng.	Var_Estab	Var_Occ	Wage Inspectors
Estabdiff	__					
Kremer-Maskin	0.90 0.000 127					
Employment Share Biomedical Engineers	-0.01 0.920 127	-0.06 0.520 127				
Var Estab	-0.05 0.560 126	-0.11 0.240 126	-0.05 0.540 126			
Var Occ	-0.08 0.360 127	-0.11 0.230 126	0.03 0.170 126	0.66 0.000 126		
Wage Inspectors	0.71 0.000 112	0.63 0.000 112	-0.04 0.660 112	-0.01 0.960 112	0.05 0.620 112	__

Medical Device Manufacturing, Size 6 & 7 Establishments

Analysis bme_3_100, All Observations, Zero inflated binomial for share Biomed

Table 2_M1: Parameter Estimates

Parameter	Unstd.	Std.	SE	Probt
	Parameter Estimates			
Estabdiff	1	1		
Kremer-Maskin	0.7176	0.93	0.03419	<.0001
Emp. Share Biomed. Er	1.3778	0.16	0.5891	0.0209
Wage Inspectors	0.6365	0.68	0.06932	<.0001
Variances				
Meas. error Kremer-M	0.004		0.0007	0.0001
Meas. Error Wage Insp	0.02		0.003	0.0001
Meas. Error Estabdiff	0.0000			
Variance latent	0.21		0.014	0.0001
-2LL =-641.1				
N=426, Subjects = 127				

Table 3_M1. R Squared Wage Variables and Employment Sha

Emp. Share Biomed. Eng.	Estabdiff	Kremer-Maskin	Wage Inspectors
0.02	1.00	0.86	0.47
(latent variable portion only)			

Table 4_M1: Model Correlations and Data Correlations
Size 6 and 7 Establishments

Model \ Data	Estabdiff	Wg Inspectors	Kremer-Maskin	Employment Share Biomed. Eng.
Estabdiff		0.71 ######### 127	0.90 0.0001 127	-0.01 0.9200 127
Wg Inspectors	0.68		0.63 0.0001 112	-0.04 0.6600 112
Kremer-Maskin	0.93	0.63		-0.06 0.5200 127
Emp. Share Biomed. Eng.	0.16	0.13	0.14	

Table 5_M1: Correlation Residuals
Size 6 and 7 Establishments
Coefficient Alpha-Comparable Analysis N=38

	Estabdiff	Wage Inspectors	Kremer-Maskin	Employment Share Biomed. Eng.
Estabdiff	__			
Wage Inspectors	-0.03			
Kremer-Maskin	0.03	0.00		
Emp. Share Biomed. Eng.	0.17	0.17	0.20	__

TABLES M2

Medical Device Manufacturing, Size 6 & 7 Establishments

Table 2_M2: Parameter Estimates				
	Parameter Estimates			
Parameter	Unstd.	Std.	SE	Probt
Estabdiff	1.0000	1.0000		
Kremer-Maskin	0.6974	0.8800	0.0468	<.0001
Emp. Share Biomed. Engineers	5.8251	0.5500	0.8356	<.0001
Wage Inspectors	0.6650	0.7000	0.0739	<.0001
Variances				
Meas. error Kremer-Maskin	0.0057		0.0013	<.0001
Meas. Error Wage Inspectors	0.0198		0.0030	<.0001
Meas. Error Estabdiff	0.0003		0.0014	0.8180
Variance latent	0.2048		0.0152	<.0001
-2LL = -670.0				
N=426, Subjects = 127				

Table 3_M2. R Squared Wage Variables and Employment Share Biomedical Engineers			
Employment Share Biomedical Engineers	Estabdiff	Kremer-Maskin	Wage Inspectors
0.30 (latent variable portion only)	0.96	0.78	0.49

Table 4_M2: Model Correlations and Data Correlations Size 6 and 7 Establishments				
Model \ Data	Estabdiff	Wg Inspectors	Kremer-Maskin	Employment Share Biomedical Eng.
Estabdiff	___	0.83 0.0001 38	0.94 0.0001 47	0.33 0.0300 47
Wg Inspectors	0.690	___	0.81 0.0001 38	0.54 0.0010 38
Kremer-Maskin	0.88	0.62	___	0.30 0.0400 47
Employment Share Biomedical Engineers	0.55	0.45	0.49	___

Correlations between the employment share of Biomedical Engineers and the other variables are taken from Analysis M3

Table 5_M2: Correlation Residuals Size 6 and 7 Establishments Coefficient Alpha-Comparable Analysis N=38				
	Estabdiff	Wage Inspectors	Kremer-Maskin	Employment Share Biomedical Eng.
Estabdiff	__			
Wage Inspectors	-0.14			
Kremer-Maskin	-0.06	-0.19		
Employment Share Biomedical Engineers	0.22	-0.09	0.19	

APPENDIX TABLES M3

Medical Device Manufacturing, Size 6 & 7 Establishments

Table 2_M3: Parameter Estimates

Parameter	Parameter Estimates Unstd.	Std.	SE	Probt
Estabdiff	1.3485	0.97	0.2666	<.0001
Kremer-Maskin	0.6364	0.58	0.1715	0.0006
Emp. Share Biomed. Engineers	9.5955	0.58	1.8501	<.0001
Wage Inspectors	1	0.7		
Variances				
Meas. error Kremer-Maskin	0.01439		0.003133	<.0001
Meas. Error Wage Inspectors	0.01795		0.004655	0.0004
Meas. Error Estabdiff	0.002			
Variance latent	0.1347		0.02837	<.0001
-2LL =49.9				
N=156, Subjects = 47				

Table 3_M3. R Squared Wage Variables and Employment Share Biomedical Engineers

Employment Share Biomedical Engineers	Estabdiff	Kremer-Maskin	Wage Inspectors
0.34 (latent variable portion only)	0.52	0.35	0.49

Table 4_M3: Model Correlations and Data Correlations
Size 6 and 7 Establishments
Coefficient Alpha-Comparable Analysis

Model \ Data	Estabdiff	Wg Inspectors	Kremer-Maskin	Employment Share Biomed. Eng.
Estabdiff	—	0.83 0.0001 38	0.94 0.0001 47	0.33 0.0300 47
Wg Inspectors	0.69	—	0.81 0.0001 38	0.54 0.0010 38
Kremer-Maskin	0.56	0.41	—	0.30 0.0400 47
Employment Share Biomedical Engineers	0.56	0.41	0.34	—

Table 5_M3: Correlation Residuals
Size 6 and 7 Establishments
Coefficient Alpha-Comparable Analysis N=38

	Estabdiff	Wage Inspectors	Kremer-Maskin	Employment Share Biomedical Eng.
Estabdiff	_			
Wage Inspectors	0.14	_		
Kremer-Maskin	0.38	0.40	_	
Employment Share Biomedical Engineers	0.23	0.13	0.04	_