A TWO-TIERED EARNINGS FRONTIER ESTIMATION OF EMPLOYER AND EMPLOYEE INFORMATION IN THE LABOR MARKET

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Abstract—This paper develops a "two-tiered frontier" estimation procedure to decompose the residual of an earnings function into three components. The first component can be interpreted as being purely random. Search theory is used to show that the other two components represent employee and employer ignorance of offer and reservation wages, respectively. Relative employee and employer ignorance estimates are presented for various population strata.

I. Introduction

IN any market, be it a commodity market or a labor market, homogeneous commodities are exchanged between buyers and sellers, often at great variations in price. Why a given commodity sells for a different price in what appears to be a competitive market depends at least in part upon the relative amounts of information buyers and sellers mutually possess about each other. In the labor market, if each potential employee knew the maximum wage offer available at each firm, and each firm knew the reservation wage of each employee, then all workers would choose the highest wage firm, and all firms would choose the lowest wage worker essentially forcing a set of dynamics leading to a unique equilibrium wage. Thus variations in wages for homogeneous workers in a competitive market at a point in time can arise when employees and employers do not have complete knowledge of the market. The result is a compensation structure with wage levels deviating from a unique equilibrium.

The fact that there appear wage variations for what are thought to be given quality workers leads one to believe that at least some participants in the market fail to possess complete information concerning the particular firm or worker associated with any particular offer or reservation wage. Employees do not know the maximum wage available to them, and employers do not know the reservation wage at which each employee would just be willing to work.

To date many take for granted the fact that employer and employee ignorance exist. In fact it is because buyers and sellers do not have full knowledge of prices that there are incentives to acquire information. Such information is so costly that less than complete information ends up being purchased, and price dispersion remains.[1]

Awareness of costly information in the labor market has stimulated a proliferation of empirical studies of job search. For the most part, these have concentrated on worker reservation wage determination[2] and search duration,[3] with much less attention being devoted to the study of employer's search efforts in finding employees.[4] The research outlined in this paper differs from past research in two ways. First, it simultaneously looks at *both* employer and employee information within a unified framework. Second, rather than concentrating on search duration it obtains measures of employee and employer information concerning reservation and offer wages directly from data on actual worker wages. Information measures are then obtained for employees and employers across various labor markets. Observed *differences* in this information from market to market are found to be consistent with theoretical expectations.

In what follows we lay out in more detail the econometric model of earnings determination which incorporates the relative roles of the employer and employee information. As shall be explained, the estimation entails a two-tiered earnings frontier. The earnings frontier is not fixed. Instead it varies with the employer's information concerning employee reservation wages and em-

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[1] See Stigler (1961). For a survey see Lippmann and McCall (1976).

[2] For example, Kasper (1967) or Kiefer-Newman (1979).

[3] For example, see Warner et al. (1980) or Yoon (1981) on unemployment duration.

[4] An exception is Barron, Bishop and Dunkelberg (1985).

ployee's information concerning offer wages. We estimate this frontier and obtain measures of differences in information between various groups of employers and employees. Section II gives an intuitive overview of the theory and develops the model. Section III provides the estimation technique along with the empirical results. Finally, section IV summarizes the paper.

II. Employer and Employee Ignorance and a Model of the Two-Tiered Earnings Frontier

Assume incomplete information in a labor market so that there is wage dispersion. From the employee viewpoint, he would be motivated to seek a job at the highest possible wage. The problem is that any potential employee is ignorant of all possible wage offers. No doubt, with full information this employee would choose the highest wage firm in the market. However, with less than full information the employee will compromise by taking only the best offer he receives. This gap between the highest available offer and the offer actually received measures *employee ignorance*.[5]

In the same manner employer ignorance can also be defined. In any market there exists a distribution of employee acceptance wages. The firm seeks to hire a given quality worker at the lowest possible wage. Knowledge of each potential employee and their associated reservation wage would enable the firm to choose the worker with the lowest reservation wage. However, without full information, it too would be forced to compromise by choosing only the cheapest worker it finds. The gap between the lowest possible reservation wage and the wage the firm actually pays measures *firm ignorance*.

The problem is that the maximum wage a firm will pay, and the minimum wage at which a worker will work are unobservables. Below we develop a methodology to incorporate these unobservables into a two-tiered earnings frontier model. As will be illustrated, nonlinear maximum likelihood estimation of the model will provide empirical measures of both employee and firm ignorance in the labor market.

[5] See Hofler and Polachek (1982) for estimation of the employee ignorance model of earnings using the conventional one-tiered frontier as in Aigner, Lovell and Schmidt (1977).

Begin by assuming a typical labor market. The demand curve is traditionally defined as the *maximum* quantity of labor demanded at any wage level, with other things held constant. To appropriately depict such a demand, let

$$Q^D = f(x^D, y) - e^D, \qquad \frac{\partial f}{\partial y} < 0 \tag{1}$$

where y equals wage; e^D is a non-negative random variable, reflecting the fact that the actual quantity demanded, Q^D, is below $f(x^D, y)$, the maximal quantity demanded at wage y; the vector x^D lists the determinants of $f(x^D, y)$ other than y.

Similarly a supply curve is defined such that the actual quantity supplied, Q^S, is below the *maximum* labor quantity, $g(x^S, y)$ which will be supplied at any wage level, y. Thus,

$$Q^S = g(x^S, y) - e^S, \qquad \frac{\partial g}{\partial y} > 0 \tag{2}$$

where x^S lists the determinants of Q^S other than y, and e^S is a non-negative random error to show that $g(x^S, y)$ is also a maximum quantity. To close the system, define an equilibrium such that

$$Q^S = Q^D. \tag{3}$$

Define by $h(\cdot)$ the non-stochastic portion of the excess demand:

$$h(x, y) \equiv f(x^D, y) - g(x^S, y) \tag{4}$$

where the vector x consists of the elements of both x^D and x^S. Thus, the equilibrium condition (3) can be rewritten as

$$h(x, y) = e^D - e^S. \tag{5}$$

Applying the Taylor expansion of $h(x, y)$ around a fixed reference point (x_0, y_0) provides

$$\begin{aligned} y = {} & (\partial h/\partial y)^{-1} \\ & \times \{[(\partial h/\partial y)y_0 + (\partial h/\partial x')x_0 \\ & \quad - h(x_0, y_0)] - (\partial h/\partial x')x \\ & \quad + (e^D - e^S)\} + R \end{aligned} \tag{6}$$

where all the derivatives are evaluated at (x_0, y_0) and R denotes the remainder term. One may choose (x_0, y_0) such that $h(x_0, y_0) = 0$, i.e., the point (x_0, y_0) is where the labor market clears under the absence of the stochastic terms e^D and e^S. Rewriting (6) in the notation of regression models, one obtains

$$y = \beta' x + u + v + w \tag{7}$$

where β denotes the coefficient vector

$$\Big((\partial h/\partial y)^{-1}[(\partial h/\partial y)y_0 + (\partial h/\partial x')x_0 - h(x_0, y_0)], \partial h/\partial x'\Big)'.$$

As defined above, the vector x lists components of both x^S and x^D, including unity as the intercept variable. Among the three random error components in (7), u consists of both the remainder term R in (6) and other purely stochastic elements. Hence, u is assumed two-sided with $E(u) = 0$. v denotes $(\partial h/\partial y)^{-1}e^D$, while w equals $-(\partial h/\partial y)^{-1}e^S$. Since $\partial f/\partial y < 0$ and $\partial g/\partial y > 0$, $\partial h/\partial y = \partial f/\partial y - \partial g/\partial y < 0$. Recall that e^D and e^S are both non-negative. Therefore,

$$v = (\partial h/\partial y)^{-1}e^D \leq 0$$

and

$$w = -(\partial h/\partial y)^{-1}e^S \geq 0.$$

Thus, it is assumed that v and w are random one-sided errors of differing signs such that $E(v) = -\mu_v < 0$ and $E(w) = \mu_w > 0$. μ_v represents the average difference between the maximum offer wages of firms (employer reservation wages) and the actual wage received by workers. In the search theory context already explored, μ_v (to be more exact, $-\mu_v$) can be interpreted as employee ignorance, showing how much *less* the employees receive than the best offer available in the market. On the other hand, μ_w represents the average difference between the actual and the minimum of employee reservation wages, and hence can be interpreted as employer ignorance.

III. Estimation of the Two-Tiered Earnings Frontier

Return to equation (7). Wage y_i is the outcome of an input vector x_i, and β is a vector of parameters. Then y_i can be specified as

$$y_i = \beta' x_i + \epsilon_i, \qquad i = 1, 2, \ldots, n \tag{8}$$

where ϵ_i is a composite error term such that

$$\epsilon_i = u_i + v_i + w_i \tag{9}$$

where $u_i \epsilon (-\infty, \infty)$, $v_i \epsilon (-\infty, 0)$, and $w_i \epsilon (0, \infty)$. Equations (8) and (9) represent a three-error component model which allows for the possibility of both systematically positive and negative components within the error structure in addition to the usual random error component.

To obtain a form suitable for estimation so that distribution of both one-sided error components v_i and w_i can be easily identified, assume that u_i has a normal distribution with zero mean and variance σ_u^2; $-v_i$ has an exponential distribution with mean μ_v, and similarly that w_i has an exponential distribution but with mean μ_w.[6] The variance of v_i and w_i are μ_v^2 and μ_w^2. In addition, for convenience, assume u_i, v_i and w_i are independent.

Suppressing the subscript i, we can show that the marginal density of ϵ_i is[7]

$$g(\epsilon) = \frac{1}{\mu_v + \mu_w} \cdot \exp\left(\frac{\epsilon}{\mu_v} + \frac{\sigma_u^2}{2\mu_v^2}\right) \cdot \left\{1 - \phi\left(\frac{\epsilon}{\sigma_u} + \frac{\sigma_u}{\mu_v}\right) + \left(1 - \phi\left(\frac{-\epsilon}{\sigma_u} + \frac{\sigma_u}{\mu_w}\right)\right) \cdot \exp\left[\frac{-1}{2}\left(\frac{2\epsilon}{\sigma_u} + \sigma_u\left(\frac{1}{\mu_v} - \frac{1}{\mu_w}\right)\right) \cdot \sigma_u\left(\frac{1}{\mu_v} + \frac{1}{\mu_w}\right)\right]\right\}, \tag{10}$$

where ϕ denotes the cumulative density (distribution) function of the standard normal random variate.

The maximum likelihood estimation of the parameters β, σ_u, μ_v and μ_w of the employee and employer ignorance model as summarized by equations (8)–(10) can be obtained by maximizing the likelihood function:

$$L(y|\beta, \sigma_u, \mu_v, \mu_w) = \prod_{i=1}^{n} g(\epsilon_i) = \prod_{i=1}^{n} g(y_i - \beta' x_i) \tag{11}$$

where the density $g(\cdot)$ is as given in (10).

[6] Choosing normal and exponential distributions guarantees identification and recovery of each parameter. In their simulation Aigner, Lovell and Schmidt (1977) find little effect on the coefficient estimates of the two-component error frontier model when using an exponential versus a normal one-sided error term. The robustness of the parameter estimates of our three-component error model needs to be probed critically in a further study. However, our preliminary check, as described in footnote 8, seems to support our model.

[7] Proof of the derivation of the marginal density (10) is available upon request from the authors.

The log-likelihood function can be written as

$$\begin{aligned}\log L = {} & n \log\left(\frac{\theta_u\theta_v\theta_w}{\theta_v + \theta_w}\right) \\ & + \left[\theta_u\theta_v\Sigma_i\epsilon_i + (n/2)\cdot\theta_v^2\right] \\ & + \Sigma_i \log\{1 - \phi(\theta_u\epsilon_i + \theta_v) \\ & \qquad + [1 - \phi(-\theta_u\epsilon_i + \theta_w)] \\ & \qquad \cdot\exp[-1/2(2\theta_u\epsilon_i + \theta_v - \theta_w) \\ & \qquad\qquad \cdot(\theta_v + \theta_w)]\}\end{aligned} \tag{12}$$

where the parameters θ_u, θ_v and θ_w are defined as follows:

$$\theta_u = 1/\sigma_u$$
$$\theta_v = \sigma_u/\mu_v$$

and

$$\theta_w = \sigma_u/\mu_w.$$

The parameter θ_u is the inverse of the dispersion (σ_u), i.e., the precision, of the two-sided error component u. The parameters θ_v and θ_w measure the inverse of the relative magnitude (with respect to σ_u) of the mean negative-sided error component v and the mean positive-sided error component w. In a search theory context θ_v and θ_w reflect relative employee and employer labor market information, while μ_v and μ_w represent employee and employer labor market ignorance. In sum, (10), reparameterized in θ_u, θ_v, and θ_w, along with (8) and (9) provide a means of estimating employer and employee information.

For estimation of the model outlined in equations (8)–(10), we use the Panel Study of Income Dynamics (PSID) data, because the large number of observations enable one to subdivide the data into a multitude of strata. Following the conventional earnings model specification, we measure the dependent variable earnings in logarithms, and use schooling, experience, experience squared, tenure and tenure squared as the explanatory factors. Thus, the earnings frontier (8) can be expressed as

$$Y_i = \log(y_i) = \beta' X_i + \epsilon_i, \qquad i = 1, 2, \ldots, n \tag{8'}$$

where y_i denotes the earnings of the i^{th} worker, x_i denotes the explanatory variables and ϵ_i is the composite three-component error term.

We estimated the above three-component error model of the earnings frontier using the data from the PSID (1981), and the results are presented in table 1.[8] In addition, ordinary least squares (OLS) estimates are presented so as to perform an additional check against traditional earnings function parameters.

The results are clear. Earnings function parameters such as the returns to schooling, experience, and tenure (measured in months) are similar between the OLS and maximum likelihood approaches. In both cases (and for both years) the returns to schooling are between 8% and 9%, which is customary for PSID generated earnings functions. Similarly, the experience and tenure parameters are as found in numerous other studies.

The beauty, of course, in using the maximum likelihood approach generated by equation (12) is that a three-term error component structure can be used to ascertain average employee (μ_v) and employer (μ_w) ignorance. As indicated, these parameters are computed from the θ_u, θ_v and θ_w coefficients, and presented in the lower half of the table. They indicate an employer ignorance of employee reservation wages of 0.405 and employee ignorance of employer offer wages of 0.284, both measured in logarithms. Though no empirical precedent exists, the results seem intuitively plausible since it is more difficult to obtain reservation wage as opposed to offer wage information.

To facilitate the interpretation of the employee and employer ignorance measures, μ_v and μ_w, we transform the earnings functions so as to express ignorance as a percentage of earnings:

$$y = \exp(\beta' x)\cdot e^u \cdot e^v \cdot e^w \tag{13}$$

and

$$E(y) = \exp(\beta' x)\cdot E(e^u)\cdot E(e^v)\cdot E(e^w) \tag{14}$$

where the subscript i is suppressed to avoid notational clutter. From (14), it is clear that $E(e^v)$ and $E(e^w)$ measure the percentage effect of employee ignorance and of employer ignorance on the ex-

[8] To test the robustness of the estimates we also looked at the 1980 data so that estimates based on completely independent observations could be compared. The estimated results for 1980, available upon request from the authors, are consistent with the reported 1981 results. This robustness of the estimates between the two years seems to provide an indirect support for our three-component error model of the earnings frontier.

TABLE 1.—PARAMETER ESTIMATES OF THE TWO-TIERED EARNINGS FRONTIER MODEL
MALE PSID DATA FOR 1981

	OLS		MLE	
	Coefficient	t-value	Coefficient	t-value
Constant	5.049	99.1	5.195	100.5
Schooling	0.085	24.9	0.0856	22.6
Experience	0.028	11.5	0.0263	5.2
Experience^2	−0.000443	−10.1	−0.000406	−13.2
Tenure	0.00371	14.6	0.00312	15.2
Tenure^2	−0.0000063	−8.6	−0.0000048	7.8
Standard Error of the Estimate[a]	0.5625			
$\theta_u = 1/\sigma_u$			4.013	19.7
$\theta_v = \sigma_u/\mu_v$			0.615	14.2
$\theta_w = \sigma_u/\mu_w$			0.878	13.1
No. of Observations	4089		4089	
R^2	0.27			
Log-likelihood			−3229.2	
σ_u			0.249	13.0
μ_v (employee ignorance)			0.405	19.7
μ_w (employer ignorance)			0.284	11.25
$E(\exp(v)) = 1/(1+\mu_v)$			0.712	
$E(\exp(w)) = 1/(1-\mu_w)$			1.400	

[a] This is the OLS estimate of the standard deviation of the error term η for the typical regression model $Y = \beta'x + \eta$ where η is a two-sided one-component error.

pected earnings. Given the assumed exponential distribution of v and w, it follows that

$$E(e^v) = 1/(1+\mu_v) \tag{15}$$

and

$$E(e^w) = 1/(1-\mu_w). \tag{16}$$

These values are also given in table 1. The results indicate that employees earn 71.2% of, and hence 28.8% less than, what they could have earned had they full information concerning maximum wages available from firms. Similarly, firms pay 40% (= 1.400 − 1) more than they otherwise would had they full information concerning employee reservation wages.

Two points about these results are worth noting. One is that just because employers pay 40% more and employees receive 30% lower wages than necessary does not require observed mean wages to deviate greatly from the full information competitive wage. Both type market inefficiencies tend to cancel. From equation (14) the estimate of the product term $E(e^v) \cdot E(e^w)$, the joint effect of both the employer and employee ignorance on earnings, is close to unity ($0.712 \times 1.4 = 0.997$). In short, market inefficiency manifests itself through wage variation and frictional unemployment. However, mean observed wage rates need not deviate from competitive wages.

The second point is that these estimates are not meant to be *absolute* measures of employer and employee ignorance. Unobserved worker and firm heterogeneity can bias upward *each* ignorance measure since it is these differences that create the necessary wage variation. For this reason, we concentrate *not* on absolute μ_v and μ_w measures, but on the *differences* in measures across strata. Because there is *less* reason for unmeasured heterogeneity to differ by strata, differences in measures *across* strata can be interpreted to reflect information differences across labor markets.[9] For this reason we concentrate on interstrata estimates, to which we now turn.

These estimates of employee and employer ignorance for detailed strata are given in table 2.[10] Males possess more market information than females (more ignorance exists for the population as a whole (0.410) than for the entirely male sample (0.405)), individuals with greater schooling possess more information than those with less schooling (0.399 versus 0.417), those in larger

[9] One approach to get at possible interstrata differences in heterogeneity is to develop panel data estimation techniques so that unobserved individual differences can be netted out of the ignorance measures. Our current research is in this area.

[10] Again, to conserve space, computations for 1980 are available upon request.

TABLE 2.—EMPLOYEE AND EMPLOYER INFORMATION (IGNORANCE) FOR VARIOUS STRATA 1981

Strata	Employee Ignorance μ_v	Employee Ignorance t-value	Employer Ignorance μ_w	Employer Ignorance t-value	Random Error σ_u	Random Error t-value	No. of Observations
Total Sample	0.410	13.5	0.303	32.8	0.270	22.7	5297
Males	0.405	13.0	0.284	19.7	0.249	11.3	4089
White Males							
Tenure, months							
< 6	0.503	0.8	0.311	6.6	0.448	1.0	799
< 15	0.480	8.7	0.329	13.3	0.387	7.2	994
< 60	0.431	10.1	0.327	18.9	0.279	14.5	1677
< 120	0.409	10.2	0.314	23.6	0.251	15.8	2112
> 120	0.326	5.5	0.210	13.0	0.161	9.3	662
White Males							
School, yrs.							
≤ 12	0.417	7.5	0.287	17.7	0.216	13.3	1567
> 12	0.399	9.4	0.285	22.7	0.211	18.1	2145
White Males							
In SMSA							
> 500,000	0.371	12.5	0.336	19.1	0.159	8.0	663
< 500,000	0.392	7.3	0.302	20.2	0.173	20.9	1741
Total Sample							
UI	0.26	6.7	0.30	5.4	0.36	7.2	526
No UI	0.42	27.6	0.30	38.3	0.26	26.8	4771
Males							
UI	0.28	7.0	0.30	5.8	0.33	8.0	432
No UI	0.41	12.5	0.27	26.8	0.24	20.3	3657
Females							
UI	[a]		[a]		[a]		
No UI	0.44	4.0	0.29	20.0	0.13	15.3	1114
Total Sample							
Union	0.28	10.4	0.19	14.2	0.21	11.6	1082
Non-Union	0.43	13.5	0.33	9.9	0.27	21.4	4215
White Males							
Union	0.21	9.0	0.19	7.0	0.18	10.2	562
Non-Union	0.43	8.3	0.31	22.5	0.24	13.6	2145
Black Males							
Union	0.27	5.8	0.21	7.9	0.22	6.8	336
Non-Union	0.39	5.7	0.33	15.1	0.24	9.7	806
Female Heads							
Union	0.26	17.5	0.08	8.7	0.26	11.5	155
Non-Union	0.45	4.6	0.29	20.4	0.14	15.6	1053

[a] Did not converge.

SMSAs have less ignorance (0.371) than those in small SMSAs (0.392), and nonunion workers are more ignorant (0.43) than union workers (0.28) as are nonrecipients of unemployment insurance (0.26 versus 0.42).

The results indicate very little difference in employer information between unemployment insurance (UI) recipients and nonrecipients. For the entire sample in 1981, essentially no difference in employer information can be discerned (the ignorance parameters are 0.30 for both the UI and non-UI group). However, the difference in information possessed by UI recipient and nonrecipient employees is large. This result easily follows from the fact that UI represents a search subsidy to employees, *not* to employers. Hence employee information increases while employer information essentially remains unchanged.

Unions, on the other hand, directly provide employee reservation wage information to firms. In fact, this function can be regarded as a primary function of unions. Wage contracts are negotiated that explicitly define wages at which each type employee will work. As such, unlike for the case of UI, it is not inconceivable to expect unions to increase employer information concerning employee pay. In fact, this is exactly what is observed for each year and strata.

Other results are less straightforward, if for no other reason than the difficulty in defining the impact of costs versus gains in information acquisition. For example, firms operating in SMSAs of greater than 500,000 appear to possess less information (0.336) than firms in smaller SMSAs (0.302). This result seems logical because in larger labor markets there is more information to acquire. However, one can similarly argue that information acquisition costs might be lower in labor markets of greater population density.[11]

IV. Summary

The research described herein incorporates notions of worker and firm ignorance in the determination and estimation of market earnings. Specifically, the earnings function is perceived as a frontier. Further, the frontier is two-tiered revealing the interaction between the employers and employees in earnings determination. An estimable model of the two-tiered earnings frontier along with nonlinear maximum likelihood procedures are developed for estimation. These procedures have been applied using the PSID data to test the plausibility of the approach. Preliminary results yield strong consistency between these measures and the implications of search theory. For this reason, we feel that the results outlined in this paper have sufficient merit to warrant further testing.

While this research does not deal explicitly with estimating buyer and seller ignorance across other markets, clearly the tools are applicable, especially if they can be adequately tested in the labor market. Moving from the labor market to commodity markets could prove valuable in understanding kinds of competition, the impact of regulatory agencies, and the effects of advertising. There might be practical applications relevant to business as well. If advertising provides information to consumers, then ad agencies could benefit by knowing relative levels of consumer ignorance across geographic and commodity markets. Since firms seek to spend their scarce advertising dollars where they will have the highest productivity, it would prove valuable for firms to advertise to consumers with the least price information. The techniques just developed could be applicable in answering these questions.

[11] Similar arguments apply to employees so that the impact of the size of the SMSA on employee information is also ambiguous a priori.

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