

PIECE RATES, FIXED WAGES AND INCENTIVES:
EVIDENCE FROM A FIELD EXPERIMENT*

Bruce Shearer
Département d'économique
Université Laval
CRÉFA and CIRANO
Québec, Québec G1K 7P4
CANADA

Bruce.Shearer@Ecn.ULaval.CA

October 2000.

Abstract

Data from a field experiment, conducted within a tree-planting firm, are used to estimate the gain in productivity that is realized when workers are paid piece rates rather than fixed wages. The experiment provides daily observations on individual worker productivity under both piece rates and fixed wages. ANOVA methods are used to estimate the incentive effect to be 20%. Since planting conditions potentially affect the incentive effect, structural econometric methods are used to generalize the experimental results to out-of-sample conditions. The structural model identifies a lower bound on the incentive effect that is estimated to be 18.5%.

* I acknowledge research support from FCAR and CIRANO. I thank participants at the Cowles Foundation Conference on the Econometrics of Strategy and Decision Making at Yale University, the Numerically Intensive Economic Policy Analysis Conference at Queens University, the Canadian Economics Association, Les journées de micro-économie appliquée the Society of Labor Economics World Congress in Milan, and the Society of Labor Economics Internet Seminar; as well as seminar participants at McGill University, New York University and the Université Laval. I also thank, without implication, Lorne Carmichael, Chris Ferrall, Paul Oyer, Harry Paarsch, Daniel Parent, John Rust and Marc Van Audenrode for helpful comments.

1. Introduction

Measuring how workers react to incentives has important implications for determining the relevance of economic theories (*e.g.* Hart and Holmstrom, 1987) as well as the personnel policies that are based on those theories (Milgrom and Roberts, 1992; Lazear, 1998). Recent empirical work in this area has concentrated on using firm-level data to measure the productivity effects of different compensation systems; *i.e.* incentive effects. Examples include Ichniowski, Shaw, and Prennushi (1997), Lazear (1996) and Paarsch and Shearer (1999, 2000) as well as Treble (1996). Of particular concern in the measurement of incentive effects is the possible endogeneity of the compensation system. Since observed compensation systems represent choices made by the firm, if factors which are unobservable to the econometrician affect both the firm's choice and worker productivity, then simple comparisons of worker performance under different compensation systems will fail to identify the incentive effect (Ehrenberg, 1990; Prendergast, 1999).

Perhaps the most direct way to solve this endogeneity problem is to gather experimental evidence. An experimental setting permits the compensation system to be varied exogenously allowing direct measurement of the incentive effect. This eliminates the need for strong functional form assumptions (Paarsch and Shearer, 1999, 2000) or assuming certain variables as instruments (Boning, Ichniowski, and Shaw, 1998) to identify the incentive effect in the data. Experimental evidence has so far concentrated on the analysis of students completing tasks on a computer under different reward systems (see, for example, Nalbantian and Schotter, 1997). While these experiments generally confirm the existence of incentive effects, generalizing their results into personnel policy may be problematic. In particular, the size of the incentive effect in the labour market depends on unknown structural parameters. Unless laboratory experiments replicate the labour market, the reactions observed within the laboratory setting will not necessarily be representative of the reactions

of workers within real firms (Wolpin, 1995). An alternative is to use the firm as a laboratory within which to conduct experiments on personnel policy. These field experiments combine the benefits of experimental economics with labour-market generated data.

This paper uses data from a field experiment to measure the gain in productivity that is realized when workers are paid piece rates rather than fixed wages. The experiment took place within a tree-planting firm operating in the province of British Columbia, Canada. The tree-planting industry is well suited to performing small scale experiments on the effects of different human-resource practices since individual daily productivity is easily observable. The firm in which the experiment was conducted usually pays its workers in proportion to the number of trees planted per day (*i.e.* a piece rate). To complete the experiment, nine male planters were randomly selected from this firm. These planters were then randomly allocated to plant under fixed wages and piece rates. Nothing else was changed in the personnel policy of the firm; the monitoring of the workers was held constant and the participating workers had no knowledge that an experiment was taking place. Each worker involved in the experiment was observed planting under both piece rates and fixed wages. In total the experiment provided 120 observations on daily productivity (60 under each compensation system).

These experimental data are used to measure the percentage difference in average productivity when workers are paid piece rates rather than fixed wages. The empirical work is based on a simple theoretical model of worker and firm behaviour under piece rates and fixed wages. The model incorporates asymmetric information over effort and specific planting conditions for a given worker, yet assumes the firm has complete knowledge of the distribution of planting conditions. The model is appealing in that its unrestricted-reduced form collapses to an ANOVA model which identifies the incentive effect on the experimental data. Results from estimating the ANOVA model suggest the incentive effect is approximately 20%.

An important issue related to experimental evidence is the generalizability of the results. In particular, the inability to randomize over all of the factors that affect experimental outcomes can limit the information provided from experimental studies (Heckman and Smith, 1995). This issue comes to light within the present context since planting conditions (particularly the difficulty of the terrain) affect worker productivity (Paarsch and Shearer, 1999) and therefore potentially affect the incentive effect. Structural econometric methods, combined with the experimental data, are used to identify out-of-sample incentive effects. Structural methods identify behavioural parameters that determine the workers' reaction to changing conditions and compensation systems. Previous applications of structural econometric methods within the compensation literature data have considered measuring the cost of moral hazard within the firm (Ferrall and Shearer, 1998 and Margiotta and Miller, forthcoming), measuring productivity profiles (Shearer, 1996), as well as measuring the incentive effect (Paarsch and Shearer, 1999, 2000). The application of structural methods to experimental data is discussed in Keane and Wolpin, 1997.

The structural model imposes non-linear restrictions on the experimental ANOVA model. Identification of the incentive effect is demonstrated under three scenarios. First, estimation of the structural model on the experimental data identifies the incentive effect within the experimental sample. Second, supplementing the experimental data with nonexperimental data and estimating the structural model on the enlarged data set identifies the incentive effect on the nonexperimental data. This holds even though the nonexperimental data contains observations on piece-rate planting only. The additional data also adds important information to the estimation of the structural model which is non-linear and includes individual-specific effects. Finally, the parameter estimates from the structural model identify a lower bound to the incentive effect which is independent of planting conditions. The lower bound is attained when the incentive effect is evaluated under a degenerate distribution of planting conditions. This result follows from the fact that worker effort is fixed under

fixed wages but generally adjusts to conditions under piece rates (since conditions affect the marginal return to effort). At zero variance the shock is constant and no adjustment takes place. When the variance is positive, however, the piece-rate worker can take advantage of large positive shocks and increase average productivity relative to that under fixed wages.

An important extension to the structural model is achieved by relaxing the assumption of perfect information to the firm over the distribution of planting conditions. Doing so allows the firm to make mistakes when judging planting conditions. These perception errors lead to a random-effects empirical specification that significantly improves the fit of the structural model.

The parameters of the model are estimated using maximum-likelihood techniques. Calculations based on the structural estimates applied to the experimental data lead to an incentive effect of 20.9%, closely matching the unrestricted ANOVA estimates. Furthermore, the lower bound to the incentive effect on non-experimental data is calculated to be 18.5%.

It is noteworthy that these results are similar to results obtained in Paarsch and Shearer (2000) which used nonexperimental, firm-level data originating from the same industry. Paarsch and Shearer calculate an incentive effect of 21% using structural econometric methods to control for a tree-planting firm's endogenous choice between piece rates and fixed wages. The results are also similar to those obtained in Lazear (1996). Lazear argued that the change in compensation system from fixed wages to piece rates in a car windshield-installing firm formed a natural experiment. His results, based on regression methods, calculated a percentage increase in productivity of 20% associated with the switch to piece rates.

There are eight additional sections to the paper. The next section discusses the institutional details of the tree-planting industry and the firm in which the experiment took place. Section 3 outlines the design of the experiment. Section 4 develops the theoretical model of productivity determination under piece rates and

fixed wages, which serves as a basis for the empirical work of the paper. Identification and estimation are discussed in Sections 5 and 6. The results are presented in Sections 7 and 8 and Section 9 concludes.

2. Institutional Details

The tree-planting industry of British Columbia is responsible for the reforestation of recently logged tracts of land. Contracts to reforest a tract of land are typically awarded to tree-planting firms through a competitive auction whereby firms will bid on the price-per-tree that they are to receive for planting. These auctions typically take place in the autumn and are conducted by either the Ministry of Forests or the major logging firms. Planting ensues the following spring.

Tree-planting firms are typically quite small, employing less than 100 planters. These planters work under the supervision of firm managers and monitors (usually in the ratio of 10 workers to one monitor). Planters are equipped with a shovel and a sack of seedlings which fit around the planter's hip. Each day they are assigned to plant trees in an area of land. To plant a tree, the planter digs a hole in the ground, places the seedling in the ground and fills the hole in.

Planting is simple yet physically exhausting work. The productivity of the planters is determined by their effort level as well as the conditions of the terrain on which they are planting. For example, if the ground is hard and rocky or covered in underbrush, it takes more time and effort to plant a given number of trees, reducing daily worker productivity. In general, planting conditions vary a great deal. Some sites have been prepared for planting, meaning that the underbrush and slash timber has been removed (often by burning the site). Other sites are unprepared and are therefore more difficult to plant.

The firm in which the experiment took place employs approximately 90 planters per year. These planters are divided into workgroups under the supervision of one of the firm's managers (who is an owner of the firm). These workgroups are assigned

to plant contracts throughout British Columbia during the planting season from February to July. The workgroup on which the experiment was performed included approximately 30 workers.

The firm typically pays its workers piece rates. Under these contracts workers are paid strictly in proportion to their individual output – no base wage is received. Planting sites are divided into blocks which are areas of homogeneous terrain. The manager in charge of the contract sets the piece rate for each block on the basis of planting conditions on that block. Typically, higher piece rates correspond to tougher planting conditions. This is because the piece rate must satisfy the worker's labour-supply constraint. Since workers are paid in proportion to their productivity and since effort is costly, workers prefer to plant in easier ground where they can plant more trees for a given effort level. To induce planters to plant on more difficult terrain the piece rate must be increased (see Paarsch and Shearer, 2000, for further details). While not a regular occurrence, some contracts are paid on a fixed wage basis. This occurs, for example, when planting conditions change a great deal between the time at which the contract is bid and the time at which it is planted. For example, the ministry of forests will sometimes unexpectedly prepare sites that have already been awarded. The firm may not have knowledge of the changed conditions until they arrive at the site to begin planting. When this occurs, rather than renegotiate the price per tree at which the contract is to be planted (which may be impossible due to time constraints), the firm will simply plant the contract under a fixed price and pay their planters fixed wages. In these cases fixed wages are determined by the planter's average wage under previous piece rate contracts.

3. Experimental Design

The goal of the experiment was to measure the change in worker effort as the compensation system changed from piece rates to fixed wages. Since worker productivity depends on worker effort as well as planting conditions, measuring the

incentive effect required changing the compensation system while holding planting conditions constant. Randomization over blocks on which to conduct the experiment proved to be impossible since the firm did not know in advance which blocks would be planted in a given year. Contracts that were planted for the ministry of forests could involve multiple years of planting. Often, the blocks that were planted in any given year were not decided upon until just before the planting was done.

Two concerns dominated the design of the experiment and the selection of blocks. The first concern was to keep the work environment as normal as possible: workers were kept ignorant of the experiment taking place. This required explaining the change in the compensation system in a manner that would seem realistic to the workers. Workers were told that certain blocks had been unexpectedly prepared and were therefore unpriced. As this is not an unknown occurrence, none of the workers involved in the experiment questioned this explanation. The second concern was the precise measurement of the incentive effect. With this in mind the blocks that were selected were large enough to allow the repeated observation of each worker planting under each compensation system.

The experiment was therefore conducted under a randomized-block design with three blocks of land. Each block was internally homogeneous in terms of planting conditions (in that the piece rate paid to workers was constant within the block) yet differed from the other two. Each block of land was randomly divided into two parts: one to be planted under piece rates and the other to be planted under fixed wages.

A group of nine male planters was randomly selected from the firm to take part in the experiment. The sample was restricted to male planters in order to reduce the variation in observed productivity. Before beginning a particular block, planters were randomly assigned to piece rates or fixed wages. Each planter then planted an equal number of days under each compensation system on that particular block of land. Attrition (one planter unexpectedly returned to school) and differing block sizes yielded different numbers of workers planting on the different blocks; subsequently not

every worker is observed on each block of land. However, any worker who is observed on a given block of land is observed under both piece rates and fixed wages on that block. Furthermore, each worker who plants on a given plot of land is observed for the same number of days (at least two) under piece rates and fixed wages.

4. Theoretical Model

This section develops a model of worker productivity under piece rates and fixed wages, incorporating the firm's choice of a piece rate. This model will form the basis of empirical work in the sections to follow. Daily productivity is determined by

$$Y = ES$$

where E represents the worker's effort level, and S is a productivity shock representing planting conditions beyond the worker's control (such as the hardness of the ground). It is assumed that S follows a lognormal distribution with parameters μ and σ^2 ; *i.e.*, $\ln S \sim N(\mu, \sigma^2)$. Workers have the utility function defined over daily wages, w , and effort, E ,

$$U_i(w, E) = w - C_i(E)$$

where $C_i(E)$ represents worker i 's monetary cost of effort and is parameterized as

$$C_i(E) = \frac{\kappa_i}{\eta} E^\eta, \quad \eta > 1, \kappa_i > 0$$

where κ_i captures individual heterogeneity, and η determines the curvature of the cost function. Alternative utility is given by \bar{u} .

4.1. Piece Rates

Under piece rates, in accordance with the observed contract, $w = rY$ where r represents the piece rate. The timing of the model is as follows. For each plot of land to be planted:

1. Nature chooses (μ, σ^2) ;
2. the firm observes (μ, σ^2) and then selects a piece rate r ;
3. the worker observes (μ, σ^2) and r and either accepts or rejects the contract;
4. conditional on accepting the contract the worker observes a particular value of S and chooses an effort level, producing Y ;
5. the firm observes Y and pays wages.

Let e_i denote the optimal level of effort chosen by worker i . Conditional on s , a realization of S ,

$$e_i = \left[\frac{rs}{\kappa_i} \right]^\gamma \quad (4.1)$$

where $\gamma = 1/(\eta - 1)$.

In order for workers to accept the contract it must satisfy their expected utility constraint. Given the contract has only one instrument and workers are heterogeneous, some workers will earn rents. It is assumed that the piece rate is chosen to satisfy the alternative utility constraint of the lowest-ability worker in the firm; that is, the worker with ability level κ_h where

$$\kappa_h = \max\{\kappa_1, \kappa_2, \dots, \kappa_n\}.$$

As such, r solves agent h 's expected utility constraint

$$\frac{r^{\gamma+1}}{\kappa_h^\gamma(\gamma+1)} \mathcal{E}(S^{(\gamma+1)}) = \bar{u} \quad (4.2)$$

where \mathcal{E} denotes the expectation operator.

Output for individual i under piece rates, conditional on s , is

$$y_i^{pr} = \left(\frac{r}{\kappa_i} \right)^\gamma s^{\gamma+1},$$

or in terms of random variables

$$Y_i^{pr} = \left(\frac{r}{\kappa_i} \right)^\gamma S^{\gamma+1}. \quad (4.3)$$

Taking logarithms of (4.2) and substituting into (4.3) gives daily productivity for individual i on contract j as

$$\ln Y_{ij}^{pr} = \ln(\gamma + 1) + \ln \bar{u} - \ln r_j + \gamma(\ln \kappa_h - \ln \kappa_i) - (\gamma + 1)^2 \frac{\sigma_j^2}{2} + \epsilon_{ij}^{pr} \quad (4.4)$$

where $\epsilon_{ij}^{pr} = (\gamma + 1)(\ln S_{ij} - \mu_j) \sim N(0, (\gamma + 1)^2 \sigma_j^2)$.

4.2. Fixed Wages

Under fixed wages worker effort is independent of the piece rate. However, given the worker is planting under the same general conditions, the piece rate that he would have received is informative as to what those conditions are. It is assumed that there is a lower bound to effort, denoted \bar{e}_i , that is enforceable within the firm. To allow effort to vary across workers in an empirically tractable manner, define

$$\bar{e}_i = \frac{\bar{\lambda}}{\kappa_i}.$$

Thus workers with lower costs of effort supply higher effort under fixed wages as well as piece rates.¹

¹ Worker effort is independent of planting conditions under fixed wages because utility is independent of conditions. This is consistent with a model in which workers are induced to supply effort through a fixed cost of being fired, incurred if their performance is unsatisfactory. This fixed cost depends on labour-market conditions which determine the probability of getting a new job. Given the short term nature of the experiment, it seems reasonable to take labour-market conditions (and fixed wage effort) to be fixed.

Worker productivity under fixed wages is therefore

$$Y_{ij}^{fw} = \frac{\bar{\lambda}}{\kappa_i} S_{ij}. \quad (4.5)$$

Taking logarithms gives

$$\ln Y_{ij}^{fw} = \ln \bar{\lambda} - \ln \kappa_i + \mu_j + \epsilon_{ij}^{fw}$$

where $\epsilon_{ij}^{fw} = \ln(S_{ij} - \mu_j) \sim N(0, \sigma_j^2)$. Substituting in from (4.2) and rearranging gives

$$\begin{aligned} \ln Y_{ij}^{fw} = & \ln \bar{\lambda} - \frac{\ln \kappa_i}{(\gamma + 1)} + \frac{\gamma}{(\gamma + 1)} (\ln \kappa_h - \ln \kappa_i) + \frac{\ln \bar{u}}{(\gamma + 1)} + \frac{\ln(\gamma + 1)}{(\gamma + 1)} \\ & - \ln r_j - (\gamma + 1) \frac{\sigma_j^2}{2} + \epsilon_{ij}^{fw}. \end{aligned} \quad (4.6)$$

5. Empirical Model

The theoretical model leads to two empirical equations defined by (4.4) and (4.6). Since both equations have mean-zero error terms it follows

$$\begin{aligned} \mathcal{E}[\ln Y + \ln r | pr, I = i, J = j] &= \ln \bar{u} + \ln(\gamma + 1) + \gamma(\ln \kappa_h - \ln \kappa_i) - (\gamma + 1)^2 \frac{\sigma_j^2}{2} \\ \mathcal{E}[\ln Y + \ln r | fw, I = i, J = j] &= \left(\ln \bar{u} + \ln(\gamma + 1) + \gamma(\ln \kappa_h - \ln \kappa_i) - \right. \\ & \quad \left. (\gamma + 1)^2 \frac{\sigma_j^2}{2} \right) \left(\frac{1}{\gamma + 1} \right) + \ln \bar{\lambda} - \frac{\ln \kappa_i}{(\gamma + 1)}. \end{aligned} \quad (5.1)$$

Without loss of generality, let $I = 1$ denote the first individual in the experimental sample and let $J = 1$ denote the first plot on which experimental planting took

place. Then using (4.4), (4.6) and (5.1), the empirical model can be written

$$\begin{aligned}
\ln Y + \ln r = & \ln \bar{u} + \ln(\gamma + 1) + \gamma(\ln \kappa_h - \ln \kappa_1) - \left(\ln \bar{u} + \ln(\gamma + 1) \right. \\
& \left. + \gamma(\ln \kappa_h - \ln \kappa_1) - \frac{(\gamma + 1)}{\gamma} \ln \bar{\lambda} + \frac{\ln \kappa_1}{\gamma} \right) \frac{\gamma}{(1 + \gamma)} DFW \\
& + \sum_{i=2}^{N_I} \gamma(\ln \kappa_1 - \ln \kappa_i) DNAME_i \\
& - \sum_{j=1}^{N_J} \frac{(\gamma + 1)^2}{2} \sigma_j^2 DBLK_j + \\
& \sum_{i=2}^{N_I} \frac{\gamma^2 - 1}{\gamma + 1} (\ln \kappa_i - \ln \kappa_1) DNAME_i \times DFW \\
& + \sum_{j=1}^{N_J} \frac{\gamma(\gamma + 1)}{2} \sigma_j^2 DBLK_j \times DFW + \epsilon_{ij}
\end{aligned} \tag{5.2}$$

where ϵ_{ij} is a mean-zero, heteroscedastic error term with

$$\text{Var}(\epsilon_{ij}) = \begin{cases} (\gamma + 1)^2 \sigma_j^2 & \text{if } DFW = 0, \\ \sigma_j^2 & \text{otherwise} \end{cases} \tag{5.3}$$

and

$$\begin{aligned}
DFW &= \begin{cases} 1 & \text{if payment is by fixed wages} \\ 0 & \text{otherwise} \end{cases} \\
DNAME_i &= \begin{cases} 1 & \text{if planting is done by individual } i \\ 0 & \text{otherwise} \end{cases} \\
DBLK_j &= \begin{cases} 1 & \text{if planting is done on block } j \\ 0 & \text{otherwise.} \end{cases}
\end{aligned}$$

The model (5.2) will be referred to as the restricted, or structural, model in that its coefficients are functions of the structural parameters of the theoretical model developed in Section 4. These functions are derived from the imposition of (4.2) which links the observed piece rate, r_j , to unobserved planting conditions (μ_j, σ_j^2) .

In unrestricted form the empirical model can be written

$$\begin{aligned}
\ln Y_{ij} + \ln r_j = & \psi_0 + \psi_1 DFW + \sum_{i=2}^{N_I} \psi_{2i} DNAME_i + \sum_{j=1}^{N_J} \psi_{3j} DBLK_j \\
& + + \sum_{i=2}^{N_I} \psi_{4i} DNAME_i \times DFW \\
& + \sum_{j=1}^{N_J} \psi_{5j} DBLK_j \times DFW + \epsilon_{ij}
\end{aligned} \tag{5.4}$$

This model is unrestricted because the behavioural restrictions implied by condition (4.2) are not imposed, thus the parameters ψ are freely estimated.

5.1. Identification in the Unrestricted Model

Identification in the unrestricted model is achieved through variation in productivity across individuals, plots and compensation systems. Not all of the coefficients ψ in (5.4) can be identified in this manner due to collinearity. The identified version of the model is

$$\begin{aligned}
\ln Y + \ln r = & \alpha_0 + \alpha_1 DFW + \sum_{i=2}^{N_I} \alpha_{2i} DNAME_i + \sum_{j=2}^{N_J} \alpha_{3j} DBLK_j + \\
& \sum_{i=2}^{N_I} \alpha_{4i} DNAME_i \times DFW + \sum_{j=2}^{N_J} \alpha_{5j} DBLK_j \times DFW + \epsilon_{ij}
\end{aligned} \tag{5.5}$$

where ϵ is a mean-zero, heteroscedastic, error term.

Note that one block-specific dummy variable must be dropped from the unrestricted model in order to avoid perfect collinearity amongst regressors. Consequently the constant term and the fixed-wage dummy absorb the variance term on the first block and the block-specific dummies estimate the differences in variances across blocks. The result is a standard ANOVA model that can easily be estimated with

linear regression techniques, allowing for the heteroscedasticity of the error term of the form

$$V(\epsilon_{ij}) = \exp(\xi_0 + \xi_1 DFW + \sum_{j=2}^3 \xi_{2j} DBLK_j + \sum_{j=2}^3 \xi_{3j} DBLK_j \times DFW). \quad (5.6)$$

The parameters are defined as

$$\begin{aligned} \alpha_0 &= \ln \bar{u} + \ln(\gamma + 1) + \gamma(\ln \kappa_h - \ln \kappa_1) - (\gamma + 1)^2 \frac{\sigma_1^2}{2} \\ \alpha_1 &= - \left(\ln \bar{u} + \ln(\gamma + 1) + \gamma(\ln \kappa_h - \ln \kappa_1) - \frac{(\gamma + 1)}{\gamma} \ln \bar{\lambda} + \right. \\ &\quad \left. \frac{\ln \kappa_1}{\gamma} - (\gamma + 1)^2 \frac{\sigma_1^2}{2} \right) \frac{\gamma}{\gamma + 1} \\ \alpha_{2i} &= \gamma(\ln \kappa_1 - \ln \kappa_i) \\ \alpha_{3j} &= \frac{(\gamma + 1)^2}{2} (\sigma_1^2 - \sigma_j^2) \\ \alpha_{4i} &= \frac{\gamma^2 - 1}{\gamma + 1} (\ln \kappa_i - \ln \kappa_1) \\ \alpha_{5j} &= \frac{\gamma(\gamma + 1)}{2} (\sigma_j^2 - \sigma_1^2). \end{aligned}$$

5.2. Identification in the Restricted Model

The restricted model imposes non linear restrictions on (5.5) that are implied by (4.2) and the choices of worker effort. This section discusses the ability of these restrictions to identify the structural parameters $(\gamma, \kappa_i, \kappa_h, \sigma_j, \mu_j, \bar{u}, \bar{\lambda})$.

Lemma 1: γ is overidentified in the structural model (5.2).

Proof: The proof follows from the fact that multiple solutions to γ exist in terms of

the parameters of (5.5). In particular,

$$\begin{aligned}\gamma &= \frac{-\alpha_{5j}}{(\alpha_{3j} + \alpha_{5j})} \\ \gamma &= \frac{\alpha_{2i} + \alpha_{4i}}{\alpha_{2i}} \\ \gamma &= \sqrt{\frac{\text{Var}(\epsilon_{ij}|DFW = 1)}{\text{Var}(\epsilon_{ij}|DFW = 0)}} - 1. \blacksquare\end{aligned}$$

Theorem 1: *The Restricted model (5.2) identifies*

- (i) γ
- (ii) σ_j^2
- (iii) $\ln \kappa_i - \ln \kappa_1$
- (iv) $\ln \bar{u} + \gamma(\ln \kappa_h - \ln \kappa_1)$
- (v) $\ln \bar{\lambda} - \ln(\kappa_1)/(\gamma + 1)$

Proof: The identification of γ follows from Lemma 1. Once these restrictions are imposed in (5.2) the variance terms identify σ_j^2 , and coefficients on the individual-specific dummies then identify $(\ln \kappa_i - \ln \kappa_1)$. The constant term identifies $\ln \bar{u} + \gamma(\ln \kappa_h - \ln \kappa_1)$ and the fixed-wage coefficient identifies $\ln \bar{\lambda} - \ln(\kappa_1)/(\gamma + 1)$. ■

6. The Incentive Effect

The incentive effect for individual i on plot j is defined as the percentage difference in expected productivity under the two compensation systems

$$h_{ij} = \frac{\mathcal{E}[Y|pr, I = i, J = j] - \mathcal{E}[Y|fw, I = i, J = j]}{\mathcal{E}[Y|fw, I = i, J = j]}. \quad (6.1)$$

The average incentive effect is then the weighted average of the incentive effects over individuals and plots:

$$H = \frac{1}{N} \sum_{i=1}^{N_I} \sum_{j=1}^{N_J} n_{ij} h_{ij} \quad (6.2)$$

where n_{ij} represents the number of observations on individual i planting on plot j .

6.1. Unrestricted

The incentive effect can be measured on the experimental data using the results from estimating (5.5). Substituting from (5.5) into (6.1) gives

$$\exp\left\{-\left(\alpha_1 + \alpha_{4i} + \alpha_{5j}\right)\right\} \times \exp\left\{.5\left(\text{Var}(\epsilon_{ij}|PR) - \text{Var}(\epsilon_{ij}|FW)\right)\right\} - 1 \quad (6.3)$$

where

$$\text{Var}(\epsilon_{ij}|PR) - \text{Var}(\epsilon_{ij}|FW) = \exp\{\xi_0 + \xi_{2j}\} \left(1 - \exp\{\xi_1 + \xi_{3j}\}\right)$$

This is simply the transformation of Halvorsen and Palmquist (1980) extended to account for the heteroscedasticity of the error term.

As with other experimental studies, ANOVA methods identify the incentive effect without recourse to structural restrictions (Burtless, 1995). Yet, (6.3) does not generalize to conditions beyond those observed in the experiment. This is because the incentive effect depends on the interaction term α_{5j} which can only be identified from a comparison of productivity under both piece rates and fixed wages on plot j . Unrestricted methods therefore require a new experiment to be performed on each plot for which the incentive effect is to be calculated. This reflects Heckman's (1995) black-box critique of reduced form analysis of experimental data.

6.2. Restricted

The incentive effect can also be calculated from the restricted model.

Lemma 2: *Conditional on a piece rate, r_j , equilibrium expected productivity under piece rates is independent of planting conditions μ_j and σ_j^2 and is given by*

$$\mathcal{E}[Y|pr, r_j, i] = \bar{u}(\gamma + 1) \left(\frac{\kappa_h}{\kappa_i}\right)^\gamma \frac{1}{r_j}. \quad (6.4)$$

Proof: The proof of Lemma 2 follows directly from substituting (4.2) into the expectation of (4.3). ■

Since the piece rate is chosen to satisfy the worker's expected utility constraint, it contains all the relevant information concerning conditions when the worker is paid piece rates.

Lemma 3: *Conditional on a piece rate, r_j , equilibrium expected productivity under fixed wages depends on planting conditions and is given by*

$$\mathcal{E}[Y|fw, r_j, i, \sigma_j] = \left[\bar{u}(\gamma + 1) \left(\frac{\kappa_h}{\kappa_i} \right)^\gamma \right]^{1/(\gamma+1)} \frac{1}{r_j} \frac{\bar{\lambda}}{\kappa_i^{1/(\gamma+1)}} \exp -(\gamma\sigma_j^2/2). \quad (6.5)$$

Proof: The proof of Lemma 2 follows directly from substituting (4.2) into the expectation of (4.5). ■

Recall that the piece rate provides information as to planting conditions through (4.2). Thus, even though worker productivity under fixed wages is independent of the piece rate, the piece rate the worker would have received had the payment system been piece rates is still informative as to the planting conditions². However, unlike the case for piece-rate planting, the piece rate does not contain all of the relevant information concerning expected productivity when workers are paid fixed wages. While planting conditions are the same under piece rates and fixed wages (for a given piece rate), the effort decision is different. In particular, under fixed wages worker effort is fixed and independent of conditions. Under piece rates, however, the value of the shock, S , determines the worker's marginal return to effort and therefore affects his effort level. As the distribution of shocks changes, the piece rate adjusts, not only

² Note, as well, \bar{u} affects $\mathcal{E}[Y|fw, r_j, i, \sigma_j]$ only through the relationship between r_j and μ_j . That is, a higher value of \bar{u} implies that a given value of r_j is associated with a larger value of μ_j (better planting conditions), leading to higher expected productivity under fixed wages.

to conditions, but also to changes in effort. This lack of symmetry between piece rates and fixed wages is reflected in the presence of the term $\exp(-\gamma\sigma_j^2)$ in (6.5), which captures the differences in worker reactions to changes in conditions, σ^2 , under piece rates and fixed wages.

Theorem 2: *The restricted equilibrium incentive effect is written*

$$\left[\bar{u}(\gamma + 1) \left(\frac{\kappa_h}{\kappa_i} \right)^\gamma \right]^{(\gamma/(\gamma+1))} \frac{\kappa_i^{1/(\gamma+1)}}{\lambda} \exp\{\gamma\sigma_j^2/2\} - 1 \quad (6.6)$$

Proof: The proof follows directly from Lemma 2 and Lemma 3.

The restricted model allows for generalizing the incentive effect to conditions beyond the experimental sample without performing separate experiments. In order to estimate the incentive effect on plot j , all that is required is an estimate of the variance for that plot, σ_j^2 , which can be recovered by observing workers under either piece rates or fixed wages. Thus nonexperimental data on piece rate planting can be used to calculate the incentive effect without observing planters under fixed wages.

To understand why the incentive effect depends on planting conditions consider Figure 1. The diagonal line PP' shows combinations of μ and σ^2 that give rise to the same piece rate for a given level of utility. From (4.2) the slope of PP' is $-(\gamma + 1)/2$. Furthermore, from Lemma 2, these same combinations of μ and σ^2 give rise to constant expected productivity under piece rates. However, from Lemma 3, the tradeoff between μ and σ^2 that keeps expected productivity under fixed wages constant is $-1/2$, the slope of FF' . Thus, conditional on r_j , the value of σ^2 affects the $\mathcal{E}[Y|FW, r, i]$ and movements along PP' change the incentive effect. Intuitively, PP' is steeper than FF' since movements along FF' indicate changes in conditions only, while movements along PP' indicate changes in conditions and effort.

At a more general level, the restricted model allows for the estimation of a lower bound to the incentive effect for *any* conditions under which the firm is planting.

Theorem 3: *A lower bound to the incentive effect for a given individual is given by evaluating (6.6) at $\sigma^2 = 0$.*

Proof: The proof follows directly from the fact that (6.6) is increasing in σ^2 .

Again, referring to Figure 1, $\mathcal{E}[Y|FW, r, i]$ is increasing along PP' in the direction towards P . The lower bound occurs at $\sigma^2 = 0$ since when conditions are constant, workers cannot adjust their effort level to changing conditions under piece rates. The lower bound is significant in that it provides information about the incentive effect for any plot of land, whether or not production data is available.

7. Data and Results

7.1. Preliminary Data Investigation and Unrestricted Results

The experimental data are presented in Table 1. The sample consists of 120 planting days, of which 60 took place under piece rates and 60 under fixed wages. The average daily productivity of these workers was 1146.67 trees and the standard deviation was 278.54. Workers were more productive under piece rates than fixed wages – the difference in average productivity being 219 trees. This represents an increase in average productivity of approximately 21 percent when workers were paid piece rates. The variance of worker output is higher under piece rates than fixed wages, reflecting the fact that workers adjust their effort to changing conditions when they are paid piece rates. Workers also earned more when planting under piece rates. To see if the increase in earnings outweighed the increase in productivity, the final column of Table 1 presents data on unit costs – daily earnings divided by daily productivity. These show that piece rates provided lower unit costs than fixed wages, the decrease being in the order of 12 percent.

Table 2 considers average productivity across the blocks used in the experiment. These blocks (denoted A , B , and C) had piece rates of \$0.17, \$0.18, and \$0.20. The average productivity under piece rates and fixed wages for each plot is given in columns 6 and 7. Notice that average productivity is higher under piece rates on each plot, although the percentage difference varies. These facts suggest that block-specific

effects are an important determinant of worker productivity and incentives, reflecting differences in planting conditions.

Average productivity per plot is given in column 4. Notice the actual average productivity is not negatively related to the piece rate as would be expected from the manner in which the firm sets piece rates. Recall, the firm sets the piece rate in inverse relation to the difficulty of the planting conditions that the manager observes. However, average productivity is higher when the piece rate is \$0.18 than when it is \$0.17. This is due to the fact that the firm sometimes errs in their judgement of planting conditions during the bidding process resulting in a piece rate that is slightly too high or too low for a given plot of land. Below, the model will be extended to account for these perception errors.

Table 3 presents average productivity by individual planter and pay system. Column 3 shows the average productivity per planter ranges from 992.5 trees to 1330 trees per day, suggesting that individual heterogeneity is present in the sample. Columns 4 and 5 give the average productivity for each planter under piece rates and fixed wages. Again average productivity for each planter is higher under piece rates.³

These data also suggest that the incentive effect varies across individuals in a systematic manner. The differences in average productivity under piece rates and fixed wages are given in column 6 of Table 3. Figure 1 graphs these differences in relation to the average productivity under piece rates (the usual compensation system). The graph clearly shows that high productivity workers are those that are most affected by the compensation system. This is captured in the structural model by the fact that high-ability workers have a lower marginal cost of effort and therefore respond greater to incentives.

Further insight into the statistical significance of the incentive effect can be

³ Averaging hides some variability in the data. In particular, analyzing individual productivity by plot and compensation system reveals that in three cases a planter planted fewer trees under piece rates than fixed wages on the same plot.

obtained by estimating (5.5) on the experimental data. The parameter estimates from this model are presented in Table 4. Evaluating (6.3) at these parameter estimates gives an estimate of the average incentive effect to be 0.199, suggesting a 20 percent increase in daily productivity on these plots when workers are paid piece rates rather than fixed wages. The bootstrapped 95 percent confidence interval for the incentive effect is [0.148, 0.250]. Since the interval does not contain zero, the incentive effect is statistically significant.

Generalizing the incentive effect beyond the experimental sample requires estimating the structural model. From Theorem 2, the incentive effect can be measured on non experimental, piece rate, plots given an estimate of the variance of conditions on those plots. To estimate these variance terms, non experimental, payroll, data is combined with the experimental data.

7.2. Non Experimental Data

The non experimental data contain observations on piece-rate planting only and includes workers who did and did not take part in the experiment. These data come from the same general contract as the experiment; *i.e.*, the manager is the same and the planting was done at the same time of the year. This ensures that labour market conditions, which might affect effort under fixed wages, are held constant throughout the sample. In an effort to eliminate outliers from the sample, only observations for which the worker worked the standard 10 hours per day were included in the sample.

The enlarged sample includes 24 workers (each of whom is observed at least 10 times) planting under 9 separate piece rates. The data cover 30 different plots of land, for each of which the manager decided on a piece rate. Evidently a number of different blocks have the same piece rate, or equivalently the same perceived conditions when the piece rate was determined. The data are presented by plot in Table 5. A couple of facts seem to confirm the importance of perception errors over actual planting conditions in the data as was noted in the discussion of the experimental data. First,

the strictly monotonic relationship between piece rates and average productivity is again broken over certain ranges of piece rates. For example, average productivity on plot 1, where the piece rate is \$0.15, is much lower than average productivity on any of the plots for which the piece rate is \$0.16. Second, average productivity varies a great deal across plots with the same piece rate.

7.3. Perception Errors

To incorporate the possibility of perception errors I allow for a difference between actual planting conditions on a particular plot, μ_j , and observed or perceived conditions on that plot $\tilde{\mu}_j$. In particular, I assume that the firm makes an unbiased estimate of actual conditions. Thus

$$\mu_j = \tilde{\mu}_j + \nu_j \quad (7.1)$$

where $\nu_j \sim N(0, \sigma_\nu^2)$ and $\mathcal{E}[\tilde{\mu}_j \nu_j] = 0$.

Given that decisions over the piece rate and labour supply depend on $\tilde{\mu}$, equation (4.4) is now written

$$\ln Y_{ij}^{pr} = \ln(\gamma + 1) + \ln \bar{u} - \ln r_j + \gamma(\ln \kappa_h - \ln \kappa_i) - (\gamma + 1)^2 \frac{(\sigma_j^2 + \sigma_\nu^2)}{2} + \epsilon_{ij}^p \quad (7.2)$$

where

$$\epsilon_{ij}^p = (\gamma + 1)(\ln S_{ij} - \mu_j + \nu_j) = \epsilon_{ij}^{pr} + (\gamma + 1)\nu_j \quad (7.3)$$

and ϵ_{ij}^{pr} is as in (4.4).

Similarly, equation (4.6) is now written

$$\begin{aligned} \ln Y_{ij}^{fw} = & \ln \bar{\lambda} - \frac{\ln \kappa_i}{(\gamma + 1)} + \frac{\gamma}{(\gamma + 1)}(\ln \kappa_h - \ln \kappa_i) + \frac{\ln \bar{u}}{(\gamma + 1)} + \frac{\ln(\gamma + 1)}{(\gamma + 1)} \\ & - \ln r_j - (\gamma + 1) \frac{(\sigma_j^2 + \sigma_\nu^2)}{2} + \epsilon_{ij}^{fw}. \end{aligned} \quad (7.4)$$

where

$$\epsilon_{ij}^f = (\ln S_{ij} - \mu_j + \nu_j) = \epsilon_{ij}^{fw} + \nu_j \quad (7.5)$$

and ϵ_{ij}^{fw} is as in (4.6).

Note that the error terms are now composed of two terms. The first, ϵ , represents deviations of a given shock from its actual mean. The second, ν , represents deviations of the actual mean from the perceived mean. Observations on the same block are now correlated through the perception error. Blocks with the same piece rate in Table 5 have the same perceived conditions, $\tilde{\mu}_j$, yet they will have different ν_j s or errors of judgement on the part of the manager.

The error structure is given by

$$\begin{aligned} \mathcal{E}[\epsilon_{ij}^p] &= 0 \\ \mathcal{E}[(\epsilon_{ij}^p)^2] &= (\gamma + 1)^2(\sigma_j^2 + \sigma_\nu^2) \\ \mathcal{E}[\epsilon_{ij}^p \epsilon_{i'j'}^p] &= 0 \\ \mathcal{E}[\epsilon_{ij}^p \epsilon_{i'j}^p] &= (\gamma + 1)^2 \sigma_\nu^2 \\ \\ \mathcal{E}[\epsilon_{ij}^f] &= 0 \\ \mathcal{E}[(\epsilon_{ij}^f)^2] &= (\sigma_j^2 + \sigma_\nu^2) \\ \mathcal{E}[\epsilon_{ij}^f \epsilon_{i'j'}^f] &= 0 \\ \mathcal{E}[\epsilon_{ij}^f \epsilon_{i'j}^f] &= \sigma_\nu^2 \quad (7.6) \\ \\ \mathcal{E}[\epsilon_{ij}^p \epsilon_{i'j'}^f] &= 0 \\ \mathcal{E}[\epsilon_{ij}^p \epsilon_{i'j}^f] &= (\gamma + 1) \sigma_\nu^2. \end{aligned}$$

In estimating the model, the variance of the perception error is allowed to vary across plots. This permits the reasonable assumption that the firm makes smaller mistakes under certain conditions than others. To capture this in a tractable manner, the following function is specified

$$\sigma_{\nu,j}^2 = \delta_0 \exp\{\delta_1 r_j\}. \quad (7.7)$$

The results are presented in Table 6. The parameters are generally precisely estimated. The elasticity of effort parameter, γ , is estimated at 1.35 which is somewhat smaller than reported in Paarsch and Shearer (1999). This may reflect differences in identification strategies. The cost of effort parameters are not all individually significant but they are jointly significant. The perception-error parameters suggest that the firm makes smaller errors at higher piece rates. This is driven by the fact that output is abnormally low when the piece rate equals \$0.15. The average standard deviation of perception errors is 0.088, suggesting that it is of the same order of magnitude as the variation in planting conditions (the average standard deviation of planting conditions is 0.078).

The value of the likelihood function is 161.11. When perception errors are ignored is this value falls to 49.65, therefore a likelihood ratio test easily rejects the null hypothesis of the absence of such errors. A test of the restriction that the variance of perception errors is constant was also performed. The value of the likelihood for that model is 158.38, giving a p-value for the null hypothesis of constant variance equal to 0.0196.

7.4. The Incentive Effect

The structural estimates in Table 7 can be used to calculate the incentive effect both within and outside the experimental sample. Substituting into (6.6) permits an estimate of the average incentive effect over all plots of land for which data is available. The results suggest the average incentive effect to be equal to 19.1%. The

incentive effect on the experimental data is calculated to be 20.9% closely matching the ANOVA estimates. Using Theorem 3, the lower bound on the incentive effect for any plot is calculated to be 18.5%. These results suggest that the incentive effect is not very sensitive to changes in planting conditions.⁴

7.5. Testing the Structural Model

In order to evaluate the performance of the structural model I compare its fit to a non structural nesting model. In particular, I estimate (5.5) on the expanded data set with the following error structure.

$$\begin{aligned}
\mathcal{E}[\epsilon_{ij}^p] &= 0 \\
\mathcal{E}[(\epsilon_{ij}^p)^2] &= (\sigma_{jp}^2 + \sigma_{pv}^2) \\
\mathcal{E}[\epsilon_{ij}^p \epsilon_{i'j'}^p] &= 0 \\
\mathcal{E}[\epsilon_{ij}^p \epsilon_{i'j}^p] &= \sigma_{vp}^2 \\
\mathcal{E}[\epsilon_{ij}^f] &= 0 \\
\mathcal{E}[(\epsilon_{ij}^f)^2] &= (\sigma_{jf}^2 + \sigma_{vf}^2) \\
\mathcal{E}[\epsilon_{ij}^f \epsilon_{i'j'}^f] &= 0 \\
\mathcal{E}[\epsilon_{ij}^f \epsilon_{i'j}^f] &= \sigma_{vf}^2 \\
\mathcal{E}[\epsilon_{ij}^p \epsilon_{i'j'}^f] &= 0 \\
\mathcal{E}[\epsilon_{ij}^p \epsilon_{i'j}^f] &= \sigma_{vpf}
\end{aligned} \tag{7.8}$$

where σ_{jp}^2 represents the variance of the error term under piece-rate planting, σ_{jf}^2 represents the variance of the error term under fixed-wage planting, σ_{vp}^2 represents the

⁴ Note that these calculations are based on averaging over the perception errors – the incentive effect on any given plot (and any given perception error) may fall below the lower bound.

variance of measurement error under piece-rate planting, $\sigma_{\nu f}^2$ represents the variance of measurement error under fixed-wage planting, and $\sigma_{\nu pf}^2$ represents the covariance between observations under piece-rate and fixed-wage planting.

This error structure permits the variance to change across plots and compensation systems in a general manner. Some restrictions are however necessary to achieve identification. In particular I impose a proportionality assumption on the perception errors under piece rates and fixed wages so that $\nu_{vf} = \gamma_2 \nu_{vp}$. This implies that the ratio of measurement error variances under piece rates and fixed wages across contracts is constant, however not necessarily equal to the ratio of the variance of productivity shocks as in the restricted model. It also implies that the covariance between piece rate and fixed wage planting on the same plot is equal to the multiplication of the respective standard deviations, as in the structural model. To complete the model, I allow the variance of the perception error to change across contracts as in the structural model; thus

$$\begin{aligned}\sigma_{vpj} &= \gamma_1 * \exp(\gamma_3 r_j) \\ \sigma_{vfj} &= \gamma_2 * \sigma_{vpj}.\end{aligned}\tag{7.9}$$

The results from estimating this model are presented in Table 7. The value of the likelihood is 178.78 and there are 58 estimated parameters.⁵ In comparison, the restricted model in Table 6 has 37 estimated parameters and the log likelihood is 161.11. This suggests that the structural model fits the data quite well. The likelihood ratio test statistic is not rejected a 1% significance level – the p-value of the test is 0.025.

⁵ There are 24 individuals in the data, nine of whom are involved in the experiment. This gives, in addition to the constant and fixed wage dummies, 23 individual-specific dummies under piece rates and 8 individual-specific dummies under fixed wages. In addition, there are 8 block-specific effects and 9 variance terms under piece rates and 2 block-specific effects and 3 variance terms under fixed wages. Finally, there are 3 terms identifying the variance of the perception error.

8. Discussion and Conclusion

This study adds to a growing body of research on measuring incentive effects. The use of experimental methods permits the direct identification of the incentive effect through a comparison of average productivity under different compensation systems. The results suggest an incentive effect of approximately 20 percent on the experimental data, and a lower bound to the incentive effect of 17 percent on the nonexperimental data.

The results also provide a useful benchmark for comparison to the results of Paarsch and Shearer (2000) which measured the incentive effect using nonexperimental data for the same occupation. The similarity of results from these two studies provides an encouraging, if preliminary, consensus. This is particularly encouraging given the differences in empirical methodology employed by the two studies; Paarsch and Shearer relied solely on structural modeling to control for the endogenous changes in compensation systems while here identification is achieved through exogenous variation within a controlled experiment. While the results are also similar to those in Lazear (1996) less can be made of this comparison since the industries and technologies are very different.

This study also demonstrates the potential value of small-scale experiments within firms to evaluate the effects of alternative human resource policies. It presents an alternative experimental methodology to previous computerized experiments on compensation systems. For example, Bull, Schotter and Weigelt (1987) chose the structural parameters of the participants cost of effort function and reward function and then considered whether actual effort choices corresponded with predicted ones. Here, the observed reaction of workers to changes in the compensation system within the experiment is used to identify the structural parameters and then policy experiments are performed based on those parameter estimates.

Finally, the results also raise some important issues and suggest directions for

future research. First, the incentive effect may be sensitive to the fixed wage that is paid to workers due to efficiency wage effects (Shapiro and Stiglitz, 1984; Macleod and Malcolmson, 1988). This could be investigated quite easily within an experimental framework by varying the wage that workers are paid under fixed wages and considering how this affects daily productivity. A related issue is why workers supply effort under fixed wages. Here, as in Lazear (1996) and Paarsch and Shearer (2000), worker effort under fixed wages is taken as a constant, to be determined empirically, rather than as an equilibrium outcome. Equilibrium models of effort determination under fixed wages are dynamic in nature and rely on the future benefits of current performance in order to enforce effort. The aforementioned efficiency wage models suggest that the threat of firing workers for shirking and the associated loss of future surplus within the firm can enforce positive effort levels under fixed wages. Models of career concerns (Fama, 1980; Gibbons and Murphy, 1992) suggest that the market's evaluation of current performance will affect future earnings and will therefore enforce a positive effort level under fixed wages. Outside opportunities are important in both these models, and equilibrium effort as well as the incentive effect may be affected by changes in these opportunities. Developing an empirically tractable dynamic model of effort determination under fixed wages which incorporates the effects of outside opportunities will provide further insights into the incentive effect.

Table 1

*Summary Statistics: Daily Productivity, Earnings and Unit Costs
Experimental Sample*

	Observations	Trees:		Earnings:	Unit Costs:
		Mean	St.Dev.	Mean	Mean
Full Sample	120	1146.67	278.54	223.78	0.20
Piece Rate	60	1256	325.27	230.85	0.186
Fixed Wages	60	1037.33	162.38	216.70	0.214

Table 2 *Summary Statistics: Average Productivity by Plot
Experimental Sample*

Plot	Obs	Rate	Mean	St.Dev.	PR	FW
<i>A</i>	24	0.17	1273.33	188.14	1390.00	1156.67
<i>B</i>	48	0.18	1321.25	247.90	1500.83	1141.67
<i>C</i>	48	0.20	908.75	143.27	944.17	873.33

Table 3

*Summary Statistics: Average Productivity, Earnings and Unit Costs, By Planter and
Pay System
Experimental Sample*

Planter	Observations	Total	PR	FW	Difference
<i>1</i>	16	1127.50	1275.00	980.00	295.00
<i>2</i>	12	1098.33	1220.00	976.67	243.33
<i>3</i>	12	1226.67	1430.00	1023.33	406.67
<i>4</i>	16	992.50	1000.00	985.00	15.00
<i>5</i>	12	1163.33	1266.67	1060.00	206.67
<i>6</i>	4	1330.00	1470.00	1190.00	280.00
<i>7</i>	16	1121.25	1165.00	1077.50	87.50
<i>8</i>	16	1157.50	1255.00	1060.00	195.00
<i>9</i>	16	1252.50	1420.00	1085.00	335.00

Table 4*Parameter Estimates of Unrestricted Model:**Experimental Sample**Sample Size = 120*

Parameter	(Coef.)	(Std. Error)	(P-Value)
α_0	4.250	0.164	0.000
α_1	-0.032	0.093	0.734
α_{22}	0.650	0.060	0.000
α_{23}	0.636	0.067	0.000
α_{24}	0.596	0.067	0.000
α_{25}	0.662	0.068	0.000
α_{26}	0.743	0.061	0.000
α_{27}	0.914	0.069	0.000
α_{28}	0.560	0.059	0.000
α_{29}	0.566	0.057	0.000
α_{32}	-0.043	0.023	0.058
α_{33}	-0.166	0.025	0.000
α_{42}	0.011	0.081	0.888
α_{43}	0.137	0.081	0.091
α_{44}	-0.194	0.057	0.001
α_{45}	0.005	0.080	0.948
α_{46}	0.004	0.070	0.951
α_{47}	-0.074	0.075	0.323
α_{48}	0.014	0.073	0.851
α_{49}	0.083	0.061	0.176
α_{52}	-0.059	0.036	0.104
α_{53}	-0.199	0.050	0.000
ξ_0	-2.760	0.187	0.000
ξ_1	0.458	0.249	0.066
ξ_{22}	-0.179	0.467	0.701
ξ_{23}	0.493	0.229	0.032
ξ_{32}	-0.723	0.590	0.220
ξ_{33}	0.149	0.319	0.639

Logarithm of the Likelihood Function: 119.097

Table 5*Summary Statistics: By Plot**Experimental and Nonexperimental Samples**Sample Size 463*

Block	Observations	Piece Rate	Mean	St.Dev.
1	10	0.15	906	199.98
2	5	0.16	1644	326.01
3	12	0.16	1693.33	600.44
4	4	0.16	1300	172.82
5	2	0.17	990	42.43
6	8	0.17	1032.50	272.54
7	2	0.17	1630	183.85
8	10	0.17	582	184.62
9	24	0.17	1273.33	188.14
10	10	0.18	1248	231.17
11	34	0.18	785.29	286.86
12	25	0.18	1403.20	279.27
13	23	0.18	1232.17	174.02
14	1	0.20	500	0.00
15	9	0.20	1571.11	263.27
16	35	0.20	994.29	287.28
17	7	0.20	1014.29	44.29
18	3	0.20	1193.33	46.19
19	8	0.20	757.50	120.68
20	28	0.20	928.57	267.85
21	13	0.20	1067.69	151.56
22	48	0.20	908.75	143.26
23	16	0.22	1185	238.05
24	6	0.22	1013.33	366.75
25	12	0.22	860	67.15
26	38	0.23	825.26	263.60
27	22	0.24	1070.91	492.21
28	22	0.24	917.27	207.14
29	24	0.28	1100	230.46
30	2	0.28	880	0.00

Table 6*Parameter Estimates : Restricted Model (Perception Errors)**Experimental and Nonexperimental Sample**Sample Size = 463*

Logarithm of the Likelihood Function: 161.11

Individual-Specific and Utility-Function Parameters

Parameter	(Coef.)	(Std. Error)	(P-Value)
a_0	5.513	0.050	0.000
a_1	-0.198	0.031	0.000
γ	1.352	0.184	0.000
$\kappa_2 - \kappa_1$	-0.002	0.048	0.966
$\kappa_3 - \kappa_1$	-0.054	0.030	0.071
$\kappa_4 - \kappa_1$	-0.014	0.031	0.641
$\kappa_5 - \kappa_1$	0.056	0.042	0.185
$\kappa_6 - \kappa_1$	0.207	0.054	0.000
$\kappa_7 - \kappa_1$	-0.054	0.036	0.132
$\kappa_8 - \kappa_1$	-0.078	0.029	0.006
$\kappa_9 - \kappa_1$	0.086	0.059	0.145
$\kappa_{10} - \kappa_1$	-0.105	0.029	0.006
$\kappa_{11} - \kappa_1$	-0.026	0.031	0.394
$\kappa_{12} - \kappa_1$	-0.168	0.046	0.000
$\kappa_{13} - \kappa_1$	0.008	0.037	0.825
$\kappa_{14} - \kappa_1$	0.141	0.045	0.002
$\kappa_{15} - \kappa_1$	-0.135	0.030	0.000
$\kappa_{16} - \kappa_1$	0.066	0.044	0.131
$\kappa_{17} - \kappa_1$	0.065	0.044	0.132
$\kappa_{18} - \kappa_1$	-0.458	0.073	0.000
$\kappa_{19} - \kappa_1$	-0.271	0.054	0.962
$\kappa_{20} - \kappa_1$	-0.145	0.039	0.000
$\kappa_{21} - \kappa_1$	-0.051	0.027	0.068
$\kappa_{22} - \kappa_1$	-0.383	0.064	0.000
$\kappa_{23} - \kappa_1$	-0.382	0.065	0.000
$\kappa_{24} - \kappa_1$	-0.459	0.072	0.000

Variance Parameters

Parameter	(Coef.)	(Std. Error)	(P-Value)
σ_1 (.15)	0.063	0.018	0.000
σ_2 (.16)	0.116	0.021	0.000
σ_3 (.17)	0.099	0.013	0.000
σ_4 (.18)	0.064	0.007	0.000
σ_5 (.20)	0.080	0.007	0.000
σ_6 (.22)	0.034	0.006	0.000
σ_7 (.23)	0.063	0.009	0.000
σ_8 (.24)	0.127	0.017	0.000
σ_9 (.28)	0.053	0.011	0.000
δ_0	0.611	0.517	0.119
δ_1	-9.918	4.233	0.010

Table 7*Parameter Estimates : Unrestricted Model**Experimental and Nonexperimental Sample**Sample Size = 463*

Logarithm of the Likelihood Function: 178.778

Individual-Specific Parameters			
Parameter	(Coef.)	(Std. Error)	(P-Value)
α_0	4.900	0.164	0.000
α_1	-0.031	0.094	0.739
$\alpha_{2,2}$	-0.014	0.068	0.837
$\alpha_{2,3}$	-0.054	0.065	0.409
$\alpha_{2,4}$	0.012	0.065	0.855
$\alpha_{2,5}$	0.093	0.067	0.167
$\alpha_{2,6}$	0.264	0.068	0.000
$\alpha_{2,7}$	-0.091	0.057	0.112
$\alpha_{2,8}$	-0.084	0.055	0.124
$\alpha_{2,9}$	0.122	0.082	0.135
$\alpha_{2,10}$	-0.171	0.052	0.001
$\alpha_{2,11}$	-0.052	0.061	0.393
$\alpha_{2,12}$	-0.246	0.064	0.000
$\alpha_{2,13}$	-0.001	0.056	0.983
$\alpha_{2,14}$	0.178	0.063	0.005
$\alpha_{2,15}$	-0.211	0.057	0.000
$\alpha_{2,16}$	0.074	0.063	0.243
$\alpha_{2,17}$	0.073	0.064	0.244
$\alpha_{2,18}$	-0.643	0.064	0.000
$\alpha_{2,19}$	-0.381	0.062	0.000
$\alpha_{2,20}$	-0.213	0.058	0.000
$\alpha_{2,21}$	-0.091	0.054	0.096
$\alpha_{2,22}$	-0.540	0.060	0.000
$\alpha_{2,23}$	-0.538	0.063	0.000
$\alpha_{2,24}$	-0.650	0.060	0.000
$\alpha_{4,2}$	0.031	0.080	0.692
$\alpha_{4,3}$	-0.029	0.076	0.703
$\alpha_{4,4}$	-0.101	0.085	0.236
$\alpha_{4,5}$	-0.018	0.071	0.802
$\alpha_{4,6}$	0.112	0.066	0.087
$\alpha_{4,7}$	0.070	0.075	0.349
$\alpha_{4,8}$	0.108	0.068	0.110
$\alpha_{4,9}$	0.090	0.070	0.189

Block-Specific Parameters

Parameter	(Coef.)	(Std. Error)	(P-Value)
$\alpha_{3,1}$	0.903	0.192	0.000
$\alpha_{3,2}$	0.428	0.178	0.017
$\alpha_{3,3}$	0.639	0.175	0.000
$\alpha_{3,4}$	0.480	0.166	0.004
$\alpha_{3,5}$	0.603	0.176	0.001
$\alpha_{3,6}$	0.613	0.207	0.003
$\alpha_{3,7}$	0.673	0.187	0.000
$\alpha_{3,8}$	0.671	0.185	0.000
$\alpha_{5,2}$	-0.163	0.103	0.113
$\alpha_{5,3}$	-0.146	0.100	0.146

Variance Parameters

Parameter	(Coef.)	(Std. Error)	(P-Value)
σ_1^p	0.151	0.039	0.000
σ_2^p	0.276	0.045	0.000
σ_3^p	0.251	0.034	0.000
σ_4^p	0.157	0.015	0.000
σ_5^p	0.172	0.012	0.000
σ_6^p	0.080	0.012	0.000
σ_7^p	0.146	0.018	0.000
σ_8^p	0.302	0.034	0.000
σ_9^p	0.125	0.023	0.000
σ_1^f	0.234	0.087	0.007
σ_2^f	0.381	0.082	0.000
σ_3^f	0.599	0.097	0.000
γ_1	0.200	0.255	0.216
γ_2	-1.915	6.364	0.764
γ_3	0.132	0.179	0.232

References

- Boning, B., C. Ichniowski, and K. Shaw, 1998. "Incentive Pay for Production Workers: An Empirical Analysis." Typescript, Carnegie Mellon University
- Burtless, G., 1995. "The Case for Randomized Field Trails in Economic and Policy Research." *Journal of Economic Perspectives*, 9(2): 63–84.
- Bull, C., A. Schotter and K. Weigelt, 1987. "Tournaments and Piece Rates: An Experimental Study." *Journal of Political Economy*, 95(1): 1–33.
- Ehrenberg, R. 1990. *Do Compensation Policies Matter?. Industrial & Labor Relations Review*, 43(3).
- Fama, E. 1980. "Agency Problems and the Theory of the Firm." *Journal of Political Economy*, 88(2): 288–307.
- Ferrall, C. and B. Shearer, 1999. "Incentives and Transaction Costs within the Firm: Estimating an Agency Model Using Payroll Records." *Review of Economic Studies*, 66(2): 309–338.
- Gibbons, R. and K. J. Murphy, 1992. "Optimal Incentive Contracts in the Presence of career Concerns: Theory and Evidence." *Journal of Political Economy*, 100(3): 468–505.
- Halvorsen, R. and R. Palmquist, 1980. "The Interpretation of Dummy Variables in Semilogarithmic Equations," *American Economic Review*, 70(3): 474–475.
- Hart, O. and B. Holmstrom. 1987. "The Theory of Contracts." In *Advances in Economic Theory Fifth World Congress*, ed. by T. Bewley. Cambridge, United Kingdom: Cambridge University Press.
- Heckman, J. and J. Smith, 1995. "Assessing the Case for Social Experiments." *Journal of Economic Perspectives*, 9(2): 85–110.
- Holmstrom, B. and P. Milgrom, 1990. "Multitask Principal-Agent Analyses: Incentive Contracts, Asset Ownership, and Job Design." *Journal of Law, Economics, & Organization*, 7(sp): 24–52.
- Ichniowski, C., K. Shaw and G. Prenzushi, 1997. "The Effects of Human Resource Management Practices on Productivity: A Study of Steel Finishing Lines." *American Economic Review*, 87(3): 291–313.
- Keane, M. and K. Wolpin, 1997. "Introduction to the *JBES* Special Issue on Structural Estimation in Applied Microeconomics." *Journal of Business and Economic Statistics*, 15(2): 111–114.

- Lazear, E. 1996. "Performance Pay and Productivity." NBER Working Paper 5672.
- Lazear, E. 1998. *Personnel Economics for Managers*. New York: John Wiley & Sons.
- Macleod, W. and J. Malcomson. 1989. "Implicit Contracts, Incentive Compatibility, and Involuntary Unemployment." *Econometrica*, 57(2): 447–480.
- Milgrom, P. and J. Roberts. 1992. *Economics, Organization and Management*. Englewood Cliffs, New Jersey: Prentice Hall.
- Nalbantian, H. and A. Schotter. 1997. "Productivity Under Group Incentives: An Experimental Study." *American Economic Review*, 87(3): 314–341.
- Paarsch, H. and B. Shearer. 1999. "The Response of Worker Effort to Piece Rates: Evidence from the British Columbia Tree-Planting Industry." *Journal of Human Resources* Fall, 1999: 643–667.
- Paarsch, H. and B. Shearer. 2000. "Piece Rates, Fixed Wages, and Incentive Effects: Statistical Evidence from Payroll Records." *International Economic Review* February, 2000: 59–92.
- Prendergast, C. 1999. "The Provision of Incentives in Firms." *Journal of Economic Literature*, XXXVII, March: 7–63.
- Shapiro, C. and J. Stiglitz. 1984. "Equilibrium Unemployment as a Worker Discipline Device." *American Economic Review*, 74(3): 433–444.
- Shearer, B. 1994. "Piece Rates, Principal-Agent Models, and Productivity Profiles: Parametric and Semi-Parametric Evidence from Payroll Records." *Journal of Human Resources*, 31(2): 275–303.
- Treble, J. 1996. "Intertemporal Substitution of Effort: Some Empirical Evidence." Typescript, Department of Economics, University of Wales, Bangor, Wales.
- Wolpin, K. 1995. *Empirical Methods for the Study of Labor Force Dynamics*. Harwood Academic Publishers.

**Figure 1: Difference in Average Trees Planted:
By Individual Planter**

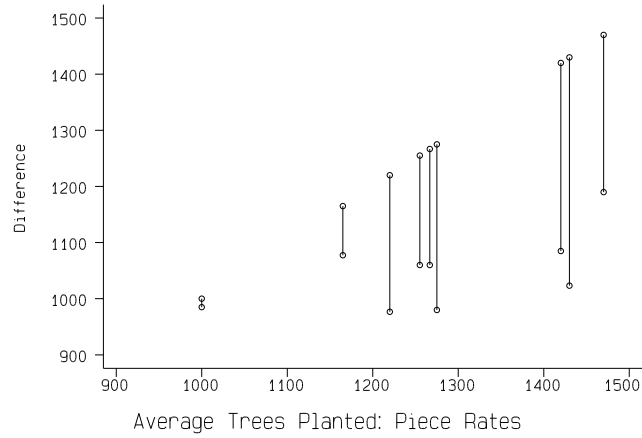


Figure 2: Expected Productivity Isoquants

