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Measuring workers' health and psychosocial work-environment on firm productivity

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Measuring workers' health and psychosocial work-environment on firm productivity [a]

by

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Abstract
We discuss a model for analyzing and measuring workers' health and psychosocial work-environment on firm productivity. Productivity is measured through the Malmquist productivity index approach using Data Envelopment Analysis. A novel component of the model is that in addition to standard quantity (or tradable) variables, we incorporate quality (or non-tradable) variables. Specifically we focus on two quality input variables: workers' health status and psychosocial work-environment. The two variables are modeled as latent or unobserved variables using Item Response Theory. Changes over time in productivity are decomposed to asses the contribution from the changes of the input quality variables. The model is illustrated using data from a worksite health promotion program conducted at three large Swedish manufacturing plants (2 paper mills, 1 steel factory) from 2000 to 2003. Over the four years we observe a general improvement in efficiency of 2-5%, out of which half can be attributed to the improvement in the quality input variables.

Keywords: Productivity, Decomposition of Efficiency, Human Resource Management, Health Status, Psychosocial Work-Environment, Ordinal Data, Latent Variables.

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1 Introduction

Partly in response to public policies and recommendations, many firms have started to invest in the health of their workers and the psychosocial work-environment. The World Health Organization, the UK Health and Safety Executive, and the European Network for Workplace Health Promotion are some examples with developed guidelines for how to implement and operationalize programs to improve health and psychosocial working environment (World Health Organization 2011, UK Health and Safety Executive 2011, European Network for Workplace Health Promotion 2011). However, beyond responding to public recommendations, firms may voluntarily make these investments in the belief that promoting health and improving the work-environment increases firm productivity and profit. Besides reducing the cost associated with absenteeism, employee turn-over, and health care coverage, the management of a firm may also believe that a healthier workforce would, b also have a positive effect on the productivity of the firm. These productivity improvements may, for instance, derive from that a healthier workforce perform better, and/or requires fewer substitute workers who comparatively may need more input (e.g. work-hours, etc.) to produce less output and of lower quality.

The objective of this paper is to discuss a model for measuring the productivity of an organization when the effect from labor quality promotion activities are included. The model provides a method for considering both overall firm productivity as well as a measurement for the contribution of the labor quality to overall firm productivity. We argue that the production process of a firm consists of two sub-processes: (1) the operational or physical production process; and, (2) the labor quality process. See *Figure 1*. Our goal is to analyze, from a firm's perspective, the overall productivity of the firm and its two sub-index of efficiency. For the measurement of firm productivity, the proposed framework draws on Data Envelopment Analysis (DEA) and Index Theory. This framework has a straightforward link to the measurement of economic performance when data consist of actual observations on inputs, outputs and quality aspects, and when the relative measure of efficiency reflects the relationship between *actual performance* and what *could be* reached, see: Afriat (1972), Charnes et al. (1994), Färe (1988), Roos (2002), Färe & Grosskopf (2004). For labor quality process, we focus on the promotion of workers' health status and the psychosocial work-environment of the firm. We model these as latent or unobservable variables using Item Response Theory (IRT). Even though IRT models are well-established and have been used extensively in Psychology and Education Research, the application to measure health status is a relatively recent development. For general comments and reviews regarding the use of IRT to measure health status and other clinical measurements, see: Cella & Chang (2000) and Reise & Waller (2009). We test our model on data from three Swedish manufacturing plants that participated in a coordinated worksite health promotion (WHP) study and implementation program from 2000 to 2003. The empirical results indicate a general improvement in efficiency of about 2-5%, out of which half can be attributed to improvement in the labor quality variables.

Social and economical effects of health are important research topics and as such have been studied extensively. Similarly firm productivity is also an important economic research topic with an extensive literature. There has so far, however, been little effort or success in properly linking the two issues. One reason for this is the challenge of collecting data that aligns workers' health and firm productivity. Studies often revert to measuring the effect of health on firm/labor productivity (or rather loss thereof) through proxies, such as absenteeism or presenteeism per employee. See, for instance, the review articles by Loeppke et al. (2003), Lofland et al. (2004), Mattke et al. (2007). Although these types of analysis and variables may be of interest in a social context, their usefulness is limited in measuring firm efficiency and productivity because these proxies measure the *means* rather than *contribution* to firm performance. For instance, a pulp mill employs and organizes the plant such that production is more or less independent of an individual's absence. Another recourse to link health and productivity is to perform the analysis on an aggregate level, such as country or region, see, for instance, Arora (2001) and Røed & Fevang (2007). This type of macro-level analysis regarding health and productivity may be of interest and importance to policy related topics, but is not germane to our objective. We seek to measure the effect at a micro-level and to decompose the productivity effect from health and other input quality aspects.

Although there are many papers that discuss various decompositions of productivity and efficiency indices, to the best of our knowledge, we are the first to show this with regard to labor quality attributes. In the economics literature, the primary focus has been on industries or countries, and how growth in labor productivity can be decomposed into factors such as technological progress, efficiency changes, and changes in the ratio between physical capital and human capital. For instance, Kumar & Russell (2002) and Henderson & Russell (2005) present index approaches to the measurement of labor productivity and how to decompose the index into factors behind changes in labor productivity at an aggregate industry or country level. In this paper, we take a more narrow view and consider firm productivity by examining the effects from labor quality activities. More directly related to our work, Färe et al. (1995), also consider the effect of quality attributes on firm productivity. The main difference is that while they consider output quality attributes, our focus is on input quality attributes and how these contribute to overall firm productivity.

The remaining paper is organized as follows. In Section 2, we present a model for measuring the efficiency and productivity performance regarding three aspects of a firm: (i) the overall firm process, (ii) the physical production process, and (iii) the labor quality process. In Section 3, we present a method for deriving and estimating labor quality attributes as latent variables, and showcase the method on workers' health status and psychosocial work-environment. In Section 4, we discuss the data used in the empirical study; and in Section 5, we present the results. Finally in Section 6, we summarize our main contributions and provide ideas for future research.

2 Measuring firm productivity and labor quality process

A firm's production process is described by observations on resources and processes. Namely, what goes into the process (input), and what comes out of the process (output). Among the input and output variables, we distinguish between those that are *traded* and those that are *non-traded*. The traded input and output variables include number of total hours worked, number of employees, amount of produced goods or services, amount of raw material, etc. The non-traded input and output variables are quality attributes, and include employee health status, psychosocial work-environment, pollution, on-time delivery, quality indicator of final product or service, etc. Note that although the non-traded variables are not physically disconnected from the traded variables and cannot, for instance, be sold individually, they are separate variables and measured independently from their counterpart traded variables. For example, a pulp mill may include tonnes of raw material (traded) and a grade quality measurement of the raw material (non-traded) as two separate input variables. Incorporating quality attributes of the labor force as non-traded input variables and to decompose this effect on firm productivity are two of the main contributions of this paper. It should however, also be stressed that the effort and time-line for making changes to the traded versus non-traded variables are significantly different. A firm may with relative little effort and time make changes to the number of employees, amount of raw material, etc. While making changes to the quality of the work force or quality of the raw material or final product may take a significant effort and time (and be costly).

We analyze the firm in terms of two sub-processes. First, the *physical production process*, which is the production of goods or services a firm can achieve from available input given decisions about production technology, short run operations, cost saving activities, production plan, etc. Second, the *labor quality process*, which are activities aimed at improving a firm's operation through promotion of the non-traded input labor quality variables or attributes. These activities are often run by the human resource department and can be seen as a separate process within the firm. Examples include worksite health promotion programs or other labor or work-environment quality promotions. Labor quality variables are non-traded variables or attributes that represent something that is good for the firm or final output and should provide value for the consumer. Although it is often understood that the higher the labor quality the better, arguably from a firm's perspective more is only better if it creates a potential for an increase in firm productivity and efficiency, *and* the firm is able to benefit from this potential. We again stress that the non-traded labor quality variables are and should be considered as separate from their counterpart traded input labor variables, such as number of employees or total work hours.

In the same way that a batch of output can be either of low or high quality, we assume that a given work force may be evaluated as more or less healthy. The motivation for considering the effect of the labor quality variables is to evaluate the potential in efficiency improvement due to possible restrictions imposed on the labor quality variables by management decisions. Therefore, the focus of our analysis is on the firm's *performance of the labor quality process* (*QP*); formally defined below in equation (3). If the labor quality variables are restricted then the performance of the labor quality process may be lower, and our *QP* measure would show what *could be reached* in terms of improvement in labor quality process efficiency and firm productivity. In other words, the proposed *QP* measures the firm's *potential improvement* in productivity, if the labor quality variables were not restricted. Note that the management decisions restricting the labor quality variables need not be deliberate or for cost saving purposes, but nevertheless may have a detrimental effect on firm productivity and efficiency. Likewise managerial decisions to improve labor quality variables may indicate that there are no restrictions imposed and that there is no room for further efficiency improvement. Therefore, with *QP* as a factor driving changes in firm productivity we are interested in whether or not *QP* comes closer to efficiency over time.

All estimations of firm performance are based on observed data and assumed to reflect what actually happened. We denote the tradable input variables by $x = (x^1, x^2, \ldots, x^N)$, the non-tradable quality input variables by $q = (q^1, q^2, \ldots, q^H)$, and the tradable and non-tradable output variables by $y = (y^1, y^2, \ldots, y^M)$. Note, the y variables include both tradable and non-tradeable output variables, and (x, q) and y may be considered the input and output vector respectively. The reason why we only separate the input variables into tradable (x) and non-tradeable (q), but not the output variable, is because we are only interested in decomposing the effect from the non-tradeable input variables. The input and output vectors at time t are denoted by (x_t, q_t) and y_t respectively, $t = 1, 2, \ldots, T$. The production technology S consist of the set of all feasible input and output vectors, $S = \{(y, x, q) | (x, q) \text{ can produce } y\}$. Following the original ideas of Farrell (1957) and successive framework of Charnes et al. (1978), we define the output based measure of technical efficiency of the physical production process at time t as follows, for (y_t, x_t, q_t),

$t = 1, 2, \ldots, T$,

$$TE_t(y_t, x_t, q_t) = \inf\{\theta | (y_t/\theta, x_t, q_t) \in S\} \tag{1}$$

In an output based approach, efficiency measures the possible increase in output for a given level of input. In other words, at time-period t, for output efficient observations $TE_t(y, x, q) = 1$, while output inefficient observations $TE_t(y, x, q) < 1$. An output based measure is motivated by the overall operating goal to fulfill incoming orders with products of sufficient quality given the available input and input quality. Note that we only have one technology for TE which is defined as the grand technology over all time-periods, and that it is assumed the technology is known to the firm at each time-period. Equation (1) is also known as a *distance function*. For more information on distance functions in the analysis of production performance see Färe (1988) and Färe & Grosskopf (2004). Given values at each time-period, we can calculate a Malmquist productivity index through the changes in efficiency over time, $\Delta TE_t \equiv TE_t(y_t, x_t, q_t)/TE_{t-1}(y_{t-1}, x_{t-1}, q_{t-1})$. Improvements over time are reflected by $\Delta TE_t > 1$.

Next we show how the output efficiency measurement can be estimated through Data Envelopment Analysis (DEA), i.e. as solutions to linear programming problems based on a non-parametric activity analysis of the firm's input and output at $t = 1, 2, \ldots, T$. Assuming constant returns to scale and free disposability, the value of the output distance function TE_t can be estimated as the solution to the following linear programming problem, for $t = 1, 2, \ldots, T$,

$$\begin{aligned}
[TE_t(y_t, x_t, q_t)]^{-1} = \max_{\theta, z}\ & \theta \\
s.t.\ x_t^n &\geq \sum_{j=1}^{T} z_j x_j^n && n = 1, 2, \ldots, N, \\
q_t^h &\geq \sum_{j=1}^{T} z_j q_j^h && h = 1, 2, \ldots, H, \\
\theta y_t^m &\leq \sum_{j=1}^{T} z_j y_j^m && m = 1, 2, \ldots, M, \\
z_j, \theta &\geq 0 && j = 1, 2, \ldots, T
\end{aligned} \tag{2}$$

where the intensity variables z_j are used to model the technology as convex combinations of input, output and quality attributes. One of the benefits with DEA as a non-parametric approach is that it does not assume a specific functional form for the frontier, and hence avoids issues associated with misspecfications. On the other hand, since all deviations from the efficient frontier are due to the deterministic modeling, the DEA framework does not allow for statistical noise, random shocks or measurement error. One alternative is to of course perform sensitivity and robustness checks by modifying or omitting the data. For brevity of the paper we have left this out.

The performance of our second process, the labor quality process, is measured in a similar way as TE. It measures the effects on firm productivity from changes in input labor quality variables. Our approach in measuring the labor quality process originates from ideas presented in Johansen (1968) regarding capacity and capacity utilization of resources. Johansen (1968) distinguishes between two concepts of capacity: (1) *plant capacity*, which he defines as 'the maximum amount that can be produced per unit of time with the existing plant and equipment, *provided that the availability of variable factors of production is not restricted*', and (2) *a synthetic concept of capacity*, which he defines as 'the maximum amount which can be produced per unit of time with the existing plant and equipment *when limitations on the availability of variable factors of production are taken into account*'.[1]

Although the focus of Johansen (1968) is on the physical capital of the production process and its relationship to labor and other non-capital input, we argue the ideas can be extended to labor quality variables, such as workers' health status and psychosocial work-environment. That is, a firm's management may be more or less successful in leveraging the effect of the input labor quality variables on the physical production process. Furthermore, as a result of programs designed to promote labor quality, management may learn over time how to leverage the potential improvements from these effects.

Based on Färe et al. (1989), measurement of capacity and capacity utilization of resources, and Färe et al. (1995), decomposition of efficiency due to output quality attributes, we define $QP_t(y_t, x_t, q_t)$ at time-period t as a ratio between values of two output

[1]The emphasis within the definitions are by Johansen.

distance functions. Namely, the output based measure of technical efficiency with and without binding restrictions on the input labor quality variables q, for $t = 1,2,\ldots,T$,

$$QP_t(y_t,x_t,q_t) = \frac{\widehat{TE}_t(y_t,x_t,q_t)}{TE_t(y_t,x_t,q_t)} \tag{3}$$

where $TE_t(y,x,q)$ is defined in (1) and estimated through (2), and $\widehat{TE}_t(y,x,q)$ is an output based distance function without restriction on the input quality attributes, and can be estimated through the following linear program, for $t = 1,2,\ldots,T$,

$$\begin{aligned}
[\widehat{TE}_t(y_t,x_t,q_t)]^{-1} = \max_{\theta,z}\ & \theta \\
s.t.\ x_t^n \geq & \sum_{j=1}^{T} z_j x_j^n \qquad n = 1,2,\ldots,N \\
\theta y_t^m \leq & \sum_{j=1}^{T} z_j y_j^m \qquad m = 1,2,\ldots,M \\
z_j, \theta \geq & \ 0 \qquad\qquad j = 1,2,\ldots,T
\end{aligned} \tag{4}$$

In other words, $\widehat{TE}_t(y,x,q)$ is derived by excluding the non-tradable quality input variables. Since the estimation of $\widehat{TE}_t(y,x,q)$ includes fewer constraints it should be fairly intuitive that $TE_t(y,x,q) \geq \widehat{TE}_t(y,x,q)$, and hence that $QP_t(y,x,q) \leq 1$. Furthermore, *if* there is a potential for improvement in the labor quality process performance then $QP_t(y,x,q) < 1$, while if there is *no* potential for improvement then $QP_t(y,x,q) = 1$. Consequently, if the labor quality process identifies a potential for improvement in labor productivity, *and* if a program can be successfully implemented to capture the potential, then we expect QP_t over time to come closer to 1.

A complimentary benefit of the solution to (4) is that it can provide 'optimal' values of the non-tradable input quality variables. Where 'optimal' refers to the level at which the non-tradable input variables do no impose restrictions on the performance of the physical production process. Using the resulting intensity variables $z_j^\star$ from the solution to (4), we can derive the 'optimal' level of each input quality variable q^h as $q^{\star h} \equiv \sum_{j=1}^{T} z_j^\star q_j^h$, $h = 1,2,\ldots,H$.

Given the measurements regarding the two sub-processes, we now define our *overall measure of firm productivity* (EQT), when the firm could freely choose the levels of input labor quality variables, as the product of the two sub-processes, for $t = 1, 2, \ldots, T$,

$$EQT_t = TE_t \times QP_t \tag{5}$$

where TE_t is the measure of production process efficiency as defined in (1) and reflects Johansen's synthetic concept of capacity, and QP_t is the labor quality process efficiency as defined in (3). In other words, the measurement of EQT is defined as the deviation from what *could be reached* in terms of overall performance and following Johansen (1968) reflects the natural definition of firm capacity. Note that it is possible to measure the overall firm productivity EQT directly by excluding the possibly restricting non-tradable input quality variables in the technology. Furthermore, any expression α can be decomposed or rewritten in terms of another expression β, as $\alpha = \beta \times (\alpha/\beta)$. However, this is only a meaningful operation if α when separated into β and α/β makes sense from an economic or managerial perspective. Since we have two sub-processes that are often run independently and with different short-term goals, we argue (5) is a meaningful decomposition. In addition, our purpose is to investigate the development of QP over time, as well as the changes in EQT over time. If there is an improvement over time, then $\Delta EQT_t \equiv EQT_t/EQT_{t-1} > 1$.

Illustrations of a firm's total efficiency measure EQT, and the measure of the two sub-processes TE and QP are provided in *Figure 2*. *Figure 2*a shows a firm where EQT improves over time due to improvement in both TE and QP. Over time, we see that the three measures come closer to efficiency. At time t the illustration shows inefficiency in the production process. In addition, the input labor quality process shows a potential for improvement if the labor quality variables are leveraged better. Over time QP improves and the potential in efficiency from an increase in q diminishes. *Figure 2*b illustrates another development over time. In this case we have a firm where EQT improves over time due to improvement in TE, but not due to QP. In fact, there is almost no gain to be made or potential benefit from the quality activities.

There are a few caveats that will help contextualize our study. First, some firms may operate under direction from the head-quarters to produce a given set of orders. For instance, a particular pulp mill may operate as an independent firm while receiving orders from head-quarters. In these situations it may be more appropriate to consider an *input based* measure of technical efficiency, where the focus is on the possible reduction in input for a given output level. That is, although it may seem mathematically arbitrary whether to use an input or output based model, the two have different result interpretations and thus better suited for different research objectives. Since we are interested in observing the possible output improvement for a given input level, as an effect of the two sub-processes in Figure *Figure 1*, an output based approach is more appropriate. In other words, for a given level of inputs, what output level is achievable? Second, we have defined productivity and efficiency as measured by quantity variables, and have not included value variables such as cost or prices. If information regarding value variables were available then the model could be extended to, for instance, cost efficiency or Luenberger indicator of profit efficiency. Third, *QP* could also be considered in terms of non-observed or latent inputs and outputs. This points to the discussion about optimal and maximal performance and what 'best observed practice' reflects; see, for instance, Morrison Paul (2000). In this paper we think of the frontier of best practice as what could be reached with no restrictions on the non-tradable input variables, which is in line with a latent approach.

Additionally, there is an important distinction between our paper and the many papers focusing on the utilization rate of the fixed physical capital. For instance, Färe et al. (1989) discusses an application to coal-fired steam-electric generating plants, with plant utilization rate varying between 30-100%. In this paper, the focus is on the labor quality process and whether the firm can do better by improving workers' health and the firm's psychosocial work-environment. Furthermore, for the firms discussed below in the empirical illustration, the labor force measured by number of employees and/or total work hours, as well as the 'utilization' is very stable over time. Consequently, we would expect to see rather small – a few per cent – but important changes over time due to increases in the labor quality variables. There is, however, a direct link between our decomposition and the one suggested by Färe et al. (1989). They suggest that a Farrell output based measure of efficiency can be decomposed into a plant capacity utilization rate and a Farrell output measure of efficiency with *variable* input freely available as follows (their equation 2.11), $K_o(x^k, u^k) = \widehat{K}_o(x^k_f, u^k) \cdot (pcu)^k$. Re-written in terms of output based distance functions and using our notation, this is equivalent to $\frac{1}{TE_t} = \frac{1}{\widehat{TE}_t} \times \frac{\widehat{TE}_t}{TE_t}$, which when re-arranged becomes $\widehat{TE}_t = TE_t \times \widehat{TE}_t / TE_t$, i.e. expression (5). Finally, as we have stressed, the production process must be able to extract the benefit from the potential that has been created by labor quality process. For instance, in the long-run the management of a firm may implement changes in the 'size' and characteristics of the labor force. The ensuing empirical analysis was done using the software program OnFront (2000).

3 Deriving and estimating labor quality variables

One of the novel aspects of our proposed firm productivity model is that we incorporate input labor quality variables. In this section, we discuss how to derive and estimate two specific labor quality variables: workers' health status and psychosocial work-environment. The reason these two are of interest is that arguably a 'healthier' workforce and 'better' work-environment could, besides reducing the costs associated with absenteeism, employee turn-over, health care coverage, etc., have a positive effect on the productivity of the firm. These productivity improvements may result because a healthier workforce performs better, and/or requires less substitute workers who comparatively may need more input to produce less output and of lower quality.

In this paper, we base firm level measurements of workers' health status and psychosocial work-environment on aggregated individual assessments of health status and psychosocial work-environment. In other words, we first derive individual values through self-reported questionnaires, and then aggregate these to create firm level values. Specifically, we model an individual worker's labor quality variable as a *latent* variable ϕ, which cannot be directly measured or observed but only indirectly observed through, for instance, self-reported questionnaires. In other words, each individual's latent labor quality variable is manifested through the responses to a set of I questions or items; where each question or item has C ordered possible answers. Although we assume the underlying labor quality variable ϕ is latent or unobservable, we need a mechanism to derive and estimate individual values of the variables. In addition, though the individual workers' response are ordinal, the overall firm level labor quality variables required for the productivity model described in Section 2 must be well-defined variables with metric properties (i.e. with well-defined unit of measure and zero). Therefore, we require a mechanism to convert individual's ordinal responses to a labor quality variable measurement with metric properties.

Motivated by work done in psychology and education theory, we base our analysis on the framework of Item Response Theory (IRT), and in particular the Graded Response Models (GRM) developed by Fumiko Samejima in the late 1960s and early 1970s. For an introduction and more details regarding IRT and GRM, see: Hays et al. (2000), Embretson & Reise (2000), Ostini & Nering (2006), and de Ayala (2009). Following the GRM framework, we assume that for a given (latent) labor quality variable ϕ, the probability a worker's response to question or item i is category c or above is given by, for $i = 1,2,\ldots,I$, $c = 1,2,\ldots,C$,

$$\Pr\{\text{response to } i \geq c|\phi\} = P^*_{i_c} = \frac{e^{\beta^i_0(\phi-\beta^i_c)}}{1+e^{\beta^i_0(\phi-\beta^i_c)}} \tag{6}$$

where β^i_0 is a slope parameter of the function for item i, and β^i_c is a location or boundary parameter for item i and category c. The slope parameter can be regarded as a discriminating or separating parameter of the item, since functions with higher values have greater accuracy in discriminating or separating people based on their underlying trait level ϕ. The location parameter specifies where along the underlying latent variable the category is 'centered'. Usually this is defined as a 'border' between category c and $c-1$. In order to have a well-defined function we set $\beta^i_1 \equiv \infty$, such that $P^*_{i_1} = 1$, $i = 1,\ldots,I$. The probability of responding to a particular category c for item i, given a (latent) labor quality variable ϕ, can then be derived by, for $i = 1,\ldots,I$,

$$\Pr\{\text{response to } i = c|\phi\} = P_{i_c} = \begin{cases} P^*_{i_c} - P^*_{i_{c+1}} & c = 1,2,\ldots,C-1 \\ P^*_{i_c} & c = C \end{cases} \tag{7}$$

A few comments follow. First, the main property that we seek to model is that workers with 'high' or 'good' values of the labor quality variables are more likely to select the higher categories of each item, while people with 'low' or 'poor' values are more likely to select the lower categories. Although it is not immediate to see this property in (6) and (7), the main reason for choosing IRT, and in particular GRM, is that it has this property. Second, the reason we employed GRM, as opposed to other IRT models, is that the underlying selection or response process of GRM is based on a person selecting between a particular category versus all the other remaining categories above it. That is, a person chooses between a particular category or moves on to something that is above. An alternative approach would be that a person selects a particular category based on only comparing it to the next adjacent category. See, for example, Pickard et al. (2007) for an application of a Rasch type IRT model to derive health status variables. Third, the estimation process for the parameters in (6) is a bit different than the usual maximum likelihood estimation process. Note that we require estimates to the beta-coefficients as well as the individual values of the underlying (independent) variable ϕ. For the purpose of this paper, we omit all details regarding the estimation process and refer the reader to Embretson & Reise (2000), Johnson (2007), and de Ayala (2009). Briefly, the estimation process is done in two-steps. First the beta-coefficients are estimated based on a marginal maximum likelihood procedure, and then, given the derived beta-coefficients, the individual ϕ are also estimated based on marginal maximum likelihood. The ensuing empirical analysis and estimation was done using the statistics software R (R Development Core Team 2010, Rizopoulos 2006).

3.1 Measuring Health status of workers

The first labor quality variable we seek to model is workers' health status. Following the framework discussed above, we model an individual worker's *health status* HS as a latent variable, which cannot be directly measured or observed but only indirectly observed through through responses to the EuroQol-5D (EQ5D) instrument (Cheung et al. 2010). The EQ5D consists of five questions pertaining to Mobility ($EQ1$), Self-Care ($EQ2$), Usual Activities ($EQ3$), Pain ($EQ4$), and Anxiety/Depression ($EQ5$); i.e. $I = 5$.

For each question there are three responses ($C = 3$), which are coded as follows: No Problem = 3, Some Problem = 2, and Major Problem = 1. The coding is done in this order, rather than the reverse which is more common, to have higher values associated with better health. As discussed above, the main property that we seek to model is that people with 'high' or 'good' health status are more likely to respond 'No Problem' (3) to each item, while people with 'low' or 'poor' health status are more likely to respond 'Major Problem' (1). Once the individual health status values have been estimated, we derive a firm level workers health by taking the arithmetic average. While other summary statistics, such as (total) sum, variance or inner quartiles, could also be appropriate, we leave this for future investigation.

3.2 Measuring psychosocial work-environment

The second input labor quality variable of interest is the firm's psychosocial work-environment. This variable is intended to capture the qualitative or 'soft' aspects of the work-environment, such as, leadership, equity, social cohesiveness, etc. These can be contrasted to the 'hard' or physical work-environment attributes, such as, exposure to toxic chemicals, noise levels, lightning conditions, etc. The assessment of the psychosocial work-environment is based on individual responses to the QPSNordic instrument (Dallner et al. 2000). The QPSNordic instrument is a questionnaire related to the perceived psychosocial work-environment. The questionnaire consists of two sets of questions: those pertaining to the psychosocial environment *of the firm*, and those pertaining to the effect of the psychosocial environment *on the individual*. For the purpose of our analysis, we only consider the firm level variables. Motivated by the underlying structural analysis recommended by Dallner et al. (2000), we focus on the questions pertaining to the following five latent aspects of psychosocial work-environment: Quantitative Work Demands (QWD), Decision Making Demands (DMD), Empowerment (EPW), Fair Leadership (FL), and Supportive Leadership (SL). For QWD there are four questions ($I = 4$), while for DMD, EPW, FL, and SL there are only three questions ($I = 3$). The specific questions for each latent variable are listed in *Table 1*. Each question has five ordered possible responses ($C = 5$), which for DMD, EPW, FL, and SL are coded as follows: Very Seldom or Never = 1, Rather Seldom = 2, Sometimes = 3, Rather Often = 4, Very Often or Always = 5. The reason for this coding is to have higher values associated with 'better' psychosocial work-environment. Therefore, the coding is reversed for QWD (Q.12, Q.13, Q.14, Q.14), as well as for question Q.91 for FL.

Similar to the Health Status variable, we first need to derive overall individual assessments of a firm's psychosocial work-environment, and then aggregate these values to an overall firm level *Psychosocial Work-Environment Index* (WEI). However, there is an added complexity with WEI, which is that it consists of five different latent aspects; i.e. QWD, DMD, EPW, FL, and SL. Therefore, our construction of WEI requires three steps. First, we estimate individual values for each of the five latent constructs. Second, we aggregate the five values into an overall individual index regarding the psychosocial work-environment. Lastly, we aggregate all the individual indices into an overall firm level Psychosocial Work-Environment Index.

The first step is done using the GRM methodology described above. Based on a Graded Response Model, we derive individual values for each of the five components QWD, DMD, EPW, FL, and SL. Let u_k be the vector of values of the five latent constructs for employee k, $u_k = (QWD_k, DMD_k, EPW_k, FL_k, SL_k)$, $k = 1, 2, \ldots, N_E$; where N_E is the number of employees. In the second step, we aggregate the five scores into a Malmquist quantity index MI_k using a two-step process. First, we derive an intermediate work-environment Malmquist quantity index, $\widehat{MI}_k$, for each individual as follows, for $k = 1, 2, \ldots, N_E$,

$$
\begin{aligned}
[\widehat{MI}_k(1, u_k)]^{-1} = \max_{v,\psi} \ & \psi \\
& s.t.\ 1 \geq \sum_{l=1}^{N_E} v_l \\
& \psi u_k^w \leq \sum_{l=1}^{N_E} v_l u_l^w \qquad w = QWD, DMD, EPW, FL, SL \\
& v_l, \psi \geq 0 \qquad \forall l
\end{aligned} \tag{8}
$$

where u_k^w is the w^{th} component of individual k's vector u_k, and v_l intensity variables used to model possible convex combinations of the five latent components. After this is done, we create a reference group based on the 20 individuals with the lowest $\widehat{MI}_k$ values, and then derive individual work-environment Malmquist quantity index, MI_k, with respect to the reference group as follows, for $k = 1, 2, \ldots, N_E$,

$$
\begin{aligned}
[MI_k(1,u_k)]^{-1} = \max_{v,\psi} \ \psi & \\
s.t.\ 1 \geq \sum_{r=1}^{20} v_r & \\
\psi u_k^w \leq \sum_{r=1}^{20} v_r u_r^w & \qquad w = QWD, DMD, EPW, FL, SL \\
v_r, \psi \geq 0 & \qquad \forall l
\end{aligned} \tag{9}
$$

where as above u_k^w is the w^{th} component of individual k's vector u_k, and v_r intensity variables used to model possible convex combinations of the reference group. The individual MI values represents how each person perceives the overall firm level psychosocial work-environment. The reason for choosing 20 as a reference group is based on a heuristic suggesting about 4 observations per variable. The reason we want a 'low' scoring reference group is to ensure the individual MI values are not bounded (by 1), and consequently to ensure that people with 'high' psychosocial work-environment scores are not censured. See Malmquist (1953) and Diewert (1983) for properties of this type of quantity index and technical justification of a reference group, and Roos & Lundström (1998) and Roos (2002) for a similar application to cataract surgery. The distance function $MI(1,u_k)$ in (9) takes the value 1 at the boundary of the reference group, and a value greater than 1 for any observation above the boundary. The third and final step in creating the firm level WEI is to take the geometric average of the individual MI values. The reason for choosing the geometric average is because the model in (9) is multiplicative and not additive. The empirical implementation of equations (8) and (9) was done using the software OnFront (2000). As with health status, we leave for future research an analysis of other summary statistics (e.g. sum, variance, or inner quartiles).

4 Input data

Data was gathered in conjunction with a worksite health promotion (WHP) study and intervention program conducted by the Karolinska Institute at three large Swedish manufacturing plants from 2000 to 2003. The study involved two paper and pulp mills, and one steel plant; labeled as Firm1, Firm2 and Firm3. Firm1, an environmentally progressive pulp mill, was among the first in the world to switch to an entirely chlorine-free pulp production. Firm2 is one of the oldest pulp mills in Sweden, and produces both paper pulp and fluff pulp. Firm3 is a world leading producer of seamless stainless steel tubes, which are used in chemical and petrochemical, oil and gas, and power generation industries. The demographic composition at the three firms were very similar: average age 45; roughly 85% male/15% female; and roughly 75% blue-collar/25% white-collar. The overall purpose with the WHP study was to develop a tool for sustainable work related health. In contrast to other WHP, which usually only focus on a specific health issue, the WHP was more comprehensive and designed to address four health and diagnostic areas, namely (1) neck and back pain; (2) cardiovascular diseases; (3) asthma and chronic pulmonary diseases; and, (4) hazardous alcohol consumption. The study also included education in sustainable health and suggestions for activities to improve health and the psychosocial work-environment. A descriptive presentation of the study and aggregated results regarding health, lifestyle and sick leave are presented in Jensen et al. (2004) and Bergström et al. (2008), some of the psychosocial work-environment data are also presented in Karlsson et al. (2010). A complimentary analysis based on a different framework of workers' health status, lifestyle and stress attributes can be found in Ødegaard & Roos (2012).

4.1 Production data

In addition to individual questionnaire data, monthly production data from the three firms was also collected over the four year WHP study period. For the purpose of our analysis, we only include production input variables related to the labor process, and did not include variables related to raw material. For Firm1 and Firm2, we consider the following input variables: 'Production Days', which is the number of days in the month, 'Number of Employees', which is the number of workers the plants employed, and 'Total Work Hours', which is the sum of the total hours the employees worked. For Firm3, the 'Number of Employees' were unfortunately inconsistently reported and had to be ignored. Therefore, for Firm3 we only include 'Total Work Hours' as the input variable. All three plants run their production process 24-7, and so 'Total Work Hours' partially varies with the number of days per month (and number of employees).

For production output variables, we consider both quantity and quality aspects. For Firm1, the specific output variables are 'Paper Pulp', which is the total amount in tonnes of softwood paper pulp produced each month, and 'Pulp Quality Index', which is an overall quality score assigned to the monthly production according to engineering established criteria. For Firm2, in addition to 'Paper Pulp' and 'Pulp Quality Index' (both defined similarly as Firm1, although the actual product and standards are different), there is a production line for fluff pulp; the total amount in tonnes produced we define by 'Fluff Pulp'. For Firm3, there are two main categories of seamless steel-tubes as defined by their respective production process: warm versus cold. Therefore, the two main output variables are 'Seamless Tubes Warm' and 'Seamless Tubes Cold', which represent the total amount in tonnes of seamless steel tubes from each of the processes. As a quality aspect of the output we consider 'Re-work Indicator', which is a measure of the amount of re-work that was needed; Re-work Indicator $\equiv$ 1/Amount of Re-Worked Steel (kg) $\times$ 100,000.

Table 2 provides descriptive statistics of the monthly production variables for each year. Firm2 is approximately 50% larger than Firm1, both in regard to input and output. While Firm2 produces almost the same amount of paper pulp as Firm1, it also produces about 17,000 tonnes of fluff pulp. For both Firm1 and Firm2, there is considerable variation with regard to both the input and output variables. Some of this variation is due to the number of days per month, and some due to changes in number of workers. Firm3 has almost twice the workforce of Firm2. We also note that Firm3 has some variation in both input and output variables. Although it may not be clear from *Table 2*, in Firm1 there is an increase over time in the amount of Paper Pulp produced, as well as a small positive trend regarding the quality. Firm2 had a small increase in Paper Pulp production, almost no change in Fluff Pulp production, and a small improvement in quality. Firm3 increased its production of Seamless Tubes Cold, decreased production of Seamless Tubes Warm, and had a small increase in quality. These development are in line with our expectations. Firm1 and Firm2 meet a fairly stable demand for their products and the production technology is 'well known'. In addition, the labor force is stable over time with small changes in age structure or skills. Firm3 is a little bit different because most orders are *make-to-order* rather than *make-to-stock*. Therefore, the observed variation does not necessarily indicate direct issues with the production process. It should also be noted that the physical production technology at Firm2 and Firm3 experienced no significant changes over the studied time period. However, Firm1 did make one partial new technology investment, namely the installment of a new 'soda ash pan'. We would expect that the possible impact from this investment mainly affected the efficiency index TE and not the QP.

4.2 Health status data

The WHP study and intervention program included ten quarterly self-reported assessments of health status. The ten quarters for each questionnaire are designated as time-period $t1, t2, \ldots, t10$. For the purpose of our productivity measurement model we only focus on the five EuroQol questions regarding Mobility ($EQ1$), Self-Care ($EQ2$), Usual Activities ($EQ3$), Pain/Discomfort ($EQ4$), and Anxiety/Depression ($EQ5$). For each time-period only questionnaires with complete responses to each of the five EQ5D questions are included. Consequently the number of responses for each time-period may vary and all employees may not be included each time. In addition, although the work-force at the three firms is relatively stable, there was employee intake and attrition.

With five questions and three responses, there are a total of 243 possible response combinations. However, empirically we only observe about 20 different response combinations at each plant. Estimation of the GRM parameters is based on the responses from all ten time-periods grouped together. After the GRM parameters have been estimated, the individual values of the latent variable health status HS (at each time-period) is estimated based on the derived GRM parameters. *Table 3* lists the slope or discriminatory parameter (β_0), and the two relevant location parameters (β_2 and β_3). We observe that the parameters are quite similar across the three firms which reflects that the response patterns are generally quite consistent across the three firms. Another noteworthy observation is that the slope parameter for $EQ5$ is relatively small and hence indicates a reduced ability in discriminating the employees. *Figure 3* displays the distribution of HS at the ten time-periods. For each time-period, the line inside the box represents the median, while the lower and upper edge of the box represents the 25^{th} and 75^{th} percentile respectively. We see that the values range from about -2.5, which represents the worst reported health status, to about .6, which represents the best reported health status and corresponds to answering 'No Problem' (3) to all five EQ5D questions. The specific value this response pattern represents is .58 for Firm1, .57 for Firm2, and .60 for Firm3. Although no one responded with 'Major Problem' (1) to all five questions, based on the beta-coefficients we can derive a value for this response pattern. This turns out to be -3.03 for Firm1, -2.92 for Firm2, and -2.83 for Firm3. Overall, in Firm1 there seems to be an improvement in health status as reflected by the increase in the median value. For Firm2 and Firm3, the results do not appear as promising; the median value is decreasing over time. One explanation for this might be due to the drop in people returning the questionnaires, particularly from people consistently reporting no health problem. In other words, there seems to be some selection bias. Although the issue of selection bias is important, we leave this for future investigation. Furthermore, we stress that our objective is not to establish statistical significance whether health status improved due to the WHP intervention study. Following the DEA framework, we seek to measure the efficiency and productivity based on observed data, which is assumed to reflect what actually happened.

Since the productivity model described in Section 2 requires non-negative variables, we make a simple transformation by shifting the Health Status values up by the amount of the lowest possible score. For each employee's Health Status we add 3.03 for Firm1, 2.92 for Firm2, and 2.83 for Firm3. To derive the firm level workers' health value we take the arithmetic average of the individual Health Status values. Recall that the EQ5D questionnaire is suppose to reflect the workers' Health Status for a given quarter. To match the quarterly Health Status data to the monthly production data we assume that for a given quarter the three monthly Health Status are the same; namely the Health Status value for that quarter. For months that were not covered by one of the 10 questionnaires, we set the Health Status to the average of the two adjacent quarterly values.

4.3 Psychosocial work-environment data

Unlike the health status questionnaire, which was administered quarterly, the psychosocial work-environment questionnaire QPSNordic was only administered three times during the WHP study: near the beginning ($T1$), middle ($T2$), and end ($T3$) of the study. For each time-period, only questionnaires with complete responses to each of the 16 QPSNordic questions were included. Consequently, the number of responses for each time-period may vary and employees may not be included all three times. Also over the study-period, there were people joining as well as leaving the firms. The number of observations (workers) with complete responses to the 16 QPSNordic questions were as follows ($T1, T2, T3$): Firm1 - 321, 309, 307; Firm2 - 389, 328, 431; Firm3 - 781, 659, 830.

Since each question has 5 possible responses, there are a total of 625 possible response combinations for QWD, and 125 possible responses combinations for the remaining four latent variables. Empirically though, across the three firms and three time periods, we only observe about 100-200 different combinations for QWD and about 50-80 different combinations for the other variables. The GRM parameters for each latent variable are estimated based on the responses from all three time-periods grouped together. *Table 4* lists for each question (item) the slope or discriminatory parameter (β_0), and the four relevant location parameters (β_2, β_3, β_4, and β_5). We observe that the parameters are quite similar across the three firms which reflects a response pattern that is generally quite consistent across the three firms. Another noteworthy observation is that the slope parameter for $Q13$ and $Q19$ for all three firms and $Q78$ for Firm2 are relatively small, indicating a smaller effect in discriminating the employees. After the GRM parameters have been estimated, the individual values of the five latent variable (for each time-period) are estimated based on the derived GRM parameters. In addition, the individual values for each latent variables are scaled up so that the worst possible response pattern corresponds to a 0 (zero).

After individual values for each of the five latent variables were estimated, we aggregated these into an overall individual psychosocial work-environment index MI_k, $k = 1,2,\ldots N_E$. As stated in Section 3.2, this is done in a two-step Malmquist quantity index approach. In the first step, we derive a reference group based on the 20 workers with ‘bad’ scores. In the second step, based on the reference group, we derive the individual *MI* values. *Figure 4* displays the distribution of the individual *MI* values at each time-period. For each time-period, the line inside the box represents the median of the observed values, while the lower and upper edge of the box represents the 25^{th} and 75^{th} percentile respectively. We observe a general improvement in the median value across all three firms, with Firm2 exhibiting the greatest relative increase. To represent the overall firm level psychosocial work-environment index (WEI), we take the geometric average of the individual *MI* values. The resulting WEI scores were as follows ($T1,T2,T3$): Firm1 - 1.456, 1.483, 1.541; Firm2 - 1.471, 1.499, 1.547; Firm3 - 1.716, 1.757, 1.768. To match the aperiodic WEI data to the monthly production data, we assume that up to the time of the next QPSNordic questionnaire the monthly WEI are the same. This roughly means that for the first 1.3 years, the monthly WEI are the first value, for the next 1.3 years the monthly WEI are the second value, and for the last 1.3 years the monthly WEI are the third value.

5 Results

Since there may be possible mismatches in the accounting of the variables, i.e. that values reported for a specific month do not correctly reflect that month, we tested the model using three month rolling averages. Thus, the first observation is March 2000 which represents the average of January, February, and March 2000, the second observation is April 2000 which represents the average of February, March, and April 2000, and so on. This was done for all variables (both input, input quality, and output variables). Furthermore, there were a few months that were excluded because the production process did not run at its regular load. The most prevalent example is July where every year Firm1 completely shuts down production, and Firm2 and Firm3 run at a significantly reduced work-load.

The result for productivity and efficiency are presented in *Figure 5*. In each graph the solid black line represents the overall firm productivity EQT, the dashed blue line the technical efficiency of the physical production TE, the dotted red line the quality process performance *QP*, and the dotted black line a simple linear regression on the *QP* values. Note that the scale on the y-axis is different for the three firms. For Firm1 and Firm3, we observe a positive trend regarding the overall productivity (EQT), while for Firm2, there seems to be very little or no change in productivity. At all three firms, we also observe periods with a decrease in productivity. The low scores for some months for Firm1 and Firm3 can partly be explained by decreases in output quality together with increases in work hours. In general, we observe over the study period that productivity increased around 2% in Firm1 and approximately 5% in Firm3. A final comment is that our results showed little or no sensitivity to the output quality variables. For instance, the results for Firm3 were very similar and consistent when output quality was measured by percentage of on-time customer delivery instead of the re-work indicator.

For our labor quality input process (*QP*), the result shows differences between the three plants. In *Figure 5*, the dotted black line represents a simple linear trend for the *QP* values. We observe that the changes for *QP* are much smaller and have less variability compared to the development of firm productivity (EQT) and efficiency of the operating production process (TE). Furthermore, we observe positive trends at Firm1 and Firm3 and almost no changes in *QP* for Firm2. The results of Firm1 and Firm3 reflect the illustration of *Figure 2*a while Firm2 reflects the illustration of *Figure 2*b. Over the entire study-period, the results indicates an increase in *QP* with about 2-3% at Firm3, and around 1% at Firm1. We, therefore, conclude that changes in overall productivity in Firm1 and Firm3 can be partially explained by the positive contribution from improvement in the labor quality process. Around half of the increase in productivity can be related to an increase in *QP*. Given the general work-environment policy at the three firms, our results are in line with what was expected. We have a positive trend for Firm1 at a relative high level, in line with a long term project aimed to improve the general work-environment. Firm3 also shows a positive trend in *QP*, which may reflect the long term project for improving the work-environment, but starts at a lower level than Firm1. The project at

Firm3 started much later than the project at Firm1, and it would have been interesting to include data from 2004 to see if the potential for improvement narrows down. Both Firm1 and Firm3 have policies for rather quick implementation of activities for improvement in the psychosocial work-environment. Firm2, on the other hand, although they too started long term work-environment projects over the study period, did not manage to implement them to the same degree. The results confirm this by showing no changes and no potential for improvement in QP, or at least that the human resource department has not been able to identify a potential. These results may change if we extend the time horizon, since the plant may learn how to create a potential for improvement in QP and productivity performance EQT.

6 Concluding remarks

We have presented a model for measuring the contribution of labor quality input on firm productivity. More specifically, we have focused on the effect of workers' health status and psychosocial work-environment. The framework of the analysis is based on the premise that there are two processes within a firm that contribute to overall productivity performance: the physical production process and the labor quality process. Although the proposed model can be seen as an extension of the traditional DEA methods for measuring efficiency and productivity, we stress that the extension to include the performance of the labor quality process is both a novel and a major contribution. Furthermore, we would also argue that the proposed firm productivity model and approach for measuring input labor quality variables, can be seen in the context of sustainability of employees work related well-being. In recent years 'sustainability' has become a much discussed topic, and to that extent our hope is that we constructively served the call made by Pfeffer (2010):

> One lesson for those interested in human sustainability is that developing a consistent set of measures or indicators of the construct, gathering data on them, and publicizing such data might provide more impetus for focusing on the human sustainability implications of what organizations do.

Another major contribution of the paper is that it has provided an alternative methodology for incorporating ordinal data into the optimization models for measuring efficiency. Based on Item Response Theory, we have modeled the labor quality aspects as latent variables. This has enabled us to construct meaningful metrics based on individual responses to self-reported ordinal questionnaires. This approach is drastically different from some of the traditional approaches that directly include the ordinal variables into the optimization models; see for example Cook & Zhu (2006). The two main reasons we chose to pursue an alternative methodology was that: (1) we wanted to separate the variable definition and variable measurement process from the firm efficiency analysis; and, (2) given individual based data we face the issue of aggregating the data to firm level. In other words, our philosophy is that the measurement of variables should be separate or exogenous from the optimization routine to estimate firm efficiency. In addition, we addressed the problem that data consisted both at a firm level and individual level. It would, however, be interesting to compare the results and implications from our approach with the more traditional approaches in incorporating ordinal data.

There are many ways to further improve the model and analysis, and the paper should be seen as a first step. For instance, one natural extension would be to include cost and/or profit efficiency, by incorporating additional data. Another potential for improvement and future research is to consider other firm level aggregations of the individual labor quality measurements. In this paper, we used arithmetic and geometric mean as a representation of the two labor quality variables, and it may be argued that other summary statistics would be more appropriate. A third interesting issue to consider would be to extend the method to higher levels of analysis, such as industry or country. This would beside the variable selection also entail a focus on data availability and index approaches for aggregation.

The model was illustrated on data from three large manufacturing firms that took part in a coordinated worksite health promotion study from 2000 to 2003. The empirical analysis indicated that at two firms there was a general positive trend regarding overall firm productivity and the labor quality process. Quite remarkably, we noted that about half of the contribution in changes of overall firm productivity can be attributed to the improvement in the performance of labor quality process. The results for the third firm indicated less tangible insights, which appears to be mainly due to a short time-frame. We, therefore, can only hypothesize that given a longer time-frame, we might be able to observe a similar positive development as with the other two firms. An objection to the empirical study could be that random fluctuation of the processes and/or measurements is not considered. In other words, the statistically inclined reader might want to establish that improvements over time of the labor quality variables are significant (statistically speaking), and that there is a causal relationship (statistically speaking) to firm productivity. Note though that the proposed model is based on the deterministic framework of DEA, and as such assumes the observed data reflect what actually happened. However, future research to account for random fluctuation of the processes and measurement error would of course be very interesting.

We end this section with some general comments regarding the work-environment and labor quality process at the three firms. The main results presented should be seen in relation to the firms' general policy regarding activities related to the work-environment. Firm1 has since the 1970s been engaged in a broad and long term project aimed at improving the work-environment. The policy at Firm1 was to quickly share results from the WHP activities to key employees, board of directors, and union representatives as well as through internal newsletters. The firms overall goal was that all employees should be involved in improving the work-environment. At Firm2, the goal was to become a world leader within the pulp industry. To reach this goal, Firm2 developed a strategy for the work-environment including psychosocial aspects, and has since 2000 been involved in a European quality assurance program. The program revolved around seven criteria (leadership, strategy, information/communication, employee development, organizational process, results and customer satisfaction). At the time of the study, the activities for improving the psychosocial work-environment had led to an improved engagement and discussions, but with little implementation at the various production units. At Firm3, various policies were implemented with the goal of ensuring that the working environment stimulates employees to work effectively and autonomously, and to promote opportunities for professional development. The results from the activities to improve the work-environment were regularly reported to the board of directors, general management, union representatives, and the internal health care unit. The goal was to have 80% of the activities implemented at the various units.

References

Afriat, S. (1972), 'Efficiency estimation of production functions', *International Economic Review* **13**, 568–598.

Arora, S. (2001), 'Health, human productivity, and long-term economic growth', *The Journal of Economic History* **61**(03), 699–749.

Bergström, G., Björklund, C., Fried, I., Lisspers, J., Nathell, L., Hermansson, U., Helander, A., Bodin, L. & Jensen, I. (2008), 'A comprehensive workplace intervention and its outcome with regard to lifestyle, health and sick leave: The aha study', *Work* **31**, 167–180.

Cella, D. & Chang, C.-H. (2000), 'A discussion of item response theory and its applications in health status assessment', *Medical Care* **38**, II66–II72.

Charnes, A., Cooper, W., Lewin, A. & Seiford, L., eds (1994), *Data envelopment analysis: Theory, methodology, and application*, Kluwer Academic Publishers, Norwell, MA, USA.

Charnes, A., Cooper, W. & Rhodes, E. (1978), 'Measuring the efficiency of decision making units', *European Journal of Operational Research* **2**, 429–444.

Cheung, K., Oemar, M., Oppe, M. & Rabin, R. (2010), User guide: Basic information on how to use EQ-5D. Version 3.0, available at: http://www.euroqol.org, accessed 2010-05-03.

Cook, W. & Zhu, J. (2006), 'Rank order data in DEA: A general framework', *European Journal of Operational Research* **174**, 1021–1038.

Dallner, M., Lindström, K., Elo, A., Skogstad, A., Gamberale, F., Hottinen, V., Knardahl, S. & Ørhede, E. (2000), Anväandarmanual för QPSNordic, frågeformulär om psykologiska och sociala faktorer i arbetslivet utprovat i Danmark, Finland, Norge och Sverige. available in Swedish at: http://www.ammuppsala.se/upload/File/FHV-metoder/QPSnordic%20manual.pdf, accessed 2010-09-21; an English version of the questionnaire is available here: https://www.qps-nordic.org/en/doc/QPSNordic_questionnaire.pdf, accessed 2010-09-21.

de Ayala, R. (2009), *Theory and Practice of Item Response Theory*, The Guilford Press, New York, New York.

Diewert, W. (1983), The theory of the cost-of-living index and the measurement of welfare change, *in* W. Diewert & C. Montmarquette, eds, 'Price Level Measurement', Statistics Canada, Ottawa, Canada, pp. 163–239.

Embretson, S. & Reise, S. (2000), *Item Response Theory for Psychologists*, Lawrence Erlbaum Associates, Inc., Mahwah, New Jersey.

European Network for Workplace Health Promotion (2011), Workplace health promotion. accessed 2011-05-13.
URL: *http://www.enwhp.org/workplace-health-promotion.html*

Färe, R. (1988), *Fundamentals of Production Theory*, Springer, USA.

Färe, R. & Grosskopf, S. (2004), *New Directions: Efficiency and Productivity*, Springer, USA.

Färe, R., Grosskopf, S. & Kokkelenberg, E. (1989), 'Measuring plant capacity, utilization and technical change: A nonparametric approach', *International Economic Review* **30**, 655–666.

Färe, R., Grosskopf, S. & Roos, P. (1995), 'Productivity and quality changes in swedish pharmacies', *International Journal of Production Economics* **39**, 137–147.

Farrell, M. (1957), 'The measurement of productive efficiency', *Journal of Royal Statistical Society, Series A (General)* **120**, 253–290.

Hays, R., Morales, L. & Reise, S. (2000), 'Item response theory and health outcomes measurement in the 21st century', *Medical Care* **38**(9), II28–II42.

Henderson, D. & Russell, R. (2005), 'Human capital and convergence: A production-frontier approach', *International Economic Review* **46**, 1167–1205.

Jensen et al. (2004), Arbete och hälsa inom process och verkstadsindustrin, aha-studien slutrapport: Del 1. Karolinska Institute, available in Swedish only at http://ki.se/content/1/c6/02/95/78/Slutrapport_AHA.pdf, accessed 2009-11-30.

Johansen, L. (1968), Production functions and the concept of capacity, *in* 'Recherches Recentes sur la Function de Production', Collection Économie Mathématique et Économétrie 2, pp. 46–72.

Johnson, M. (2007), 'Marginal maximum likelihood estimation of item response models in R', *Journal of Statistical Software* **20**, 1–24.

Karlsson, M., Björklund, C. & Jensen, I. (2010), 'The effects of psychosocial work factors on production loss, and the mediating effect on employee health', *Journal of Occupational and Environmental Medicine* **52**, 310–317.

Kumar, S. & Russell, R. (2002), 'Technological change, technological catch-up, and capital deepening: Relative contributions to growth and convergence', *The American Economic Review* **92**, 527–548.

Loeppke, R., Hymel, P., Lofland, J., Pizzi, L., Konicki, D., Anstadt, G., Baase, C., Fortuna, J. & Scharf, T. (2003), 'Health-related workplace productivity measurement: General and migraine-specific recommendations from the acoem expert panel', *Journal of Occupational and Environmental Medicine* **45**, 349–359.

Lofland, J., Pizzi, L. & Frick, K. (2004), 'A review of health-related workplace productivity loss instruments', *PharmacoEconomics* **22**(3), 165–184.

Malmquist, S. (1953), 'Index numbers and indifference surfaces', *Trabajos de Estadística y de Investigación Operativa* **4**, 209–242.

Mattke, S., Balakrishnan, A., Bergamo, G. & Newberry, S. (2007), 'A review of methods to measure health-related productivity loss', *The American Journal of Managed Care* **13**, 211–217.

Morrison Paul, C. (2000), Thoughts on productivity, efficiency, and capacity utilization measurement for fisheries. UC Davis, Department of Agricultural and Resource Economics Working Paper #00-031, available at: http://arelibrary.ucdavis.edu/working_papers/files/00-031.pdf, accessed 2010-10-12.

Ødegaard, F. & Roos, P. (2012), 'Measuring worksite health promotion programs: an application of structural equation modeling with ordinal data', *European Journal of Health Economics* . forthcoming.

OnFront (2000), *OnFront 2.02: The Professional Tool for Efficiency and Productivity Measurement*, Economic Measurement and Quality Corporation AB, Lund, Sweden. the software is no longer supported.

Ostini, R. & Nering, M. (2006), *Polytomous Item Response Theory Models*, Sage Publications, Thousand Oaks, California.

Pfeffer, J. (2010), 'Building sustainable organizations: The human factor', *The Academy of Management Perspectives* **24**, 34–45.

Pickard, A., De Leon, M., Kohlmann, T., Cella, D. & Rosenbloom, S. (2007), 'Psychometric comparison of the standard eq-5d to a 5 level version in cancer patients', *Medical Care* **45**, 259–263.

R Development Core Team (2010), *R: A Language and Environment for Statistical Computing*, R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, http://www.R-project.org.

Reise, S. & Waller, N. (2009), 'Item response theory and clinical measurement', *Annual Review of Clinical Psychology* **5**, 27–48.

Rizopoulos, D. (2006), 'ltm: An R package for latent variable modeling and item response theory analyses', *Journal of Statistical Software* **17**, 1–25.

Røed, K. & Fevang, E. (2007), 'Organizational change, absenteeism, and welfare dependency', *Journal of Human Resources* **XLII**(1), 156–193.

Roos, P. (2002), Measuring output of hospital services, *in* K. J. Fox, ed., 'Efficiency in the Public Sector', Kluwer Academic Publishers, Norwell, MA, USA.

Roos, P. & Lundström, M. (1998), 'An index approach for the measurement of patient benefits from surgery - illustrated in the case of cataract extraction', *Information Systems and Operational Research* **36**, 120–128.

UK Health and Safety Executive (2011), What are the management standards. accessed 2011-05-13.
URL: *http://www.hse.gov.uk/stress/standards/*

World Health Organization (2011), Launching healthy workplaces: a global model for action on the occasion of the world day for health and safety at work. accessed 2011-05-13.
URL: *http://www.who.int/occupational_health/healthy_workplaces/en/index.html*

Tables and Figures

Table 1: The QPSNordic questions for the five psychosocial work-environment constructs Quantitative Work Demands (QWD), Decision Making Demands (DMD), Empowerment (EPW), Fair Leadership (FL), and Supportive Leadership (SL)

QWD	Q12.	Is your work load irregular so that work piles up?
	Q13.	Do you have to work overtime?
	Q14.	Is it necessary to work at a rapid pace?
	Q15.	Do you have too much to do?
DMD	Q17.	Does your work require quick decisions?
	Q19.	Does your work require maximum attention?
	Q22.	Does your work require complex decisions?
EPW	Q84.	Does your immediate superior encourage you to participate in important decisions?
	Q85.	Does your immediate superior encourage your to speak up, when you have different opinions?
	Q86.	Does your immediate superior help you develop your skills?
FL	Q89.	Does your immediate superior distribute the work fairly and impartially?
	Q90.	Does your immediate superior treat the workers fairly and equally?
	Q91.	Is the relationship between you and your immediate superior a source of stress to you?
SL	Q73.	If needed, can you get support and help with your work from your immediate superior?
	Q75.	If needed, is your immediate superior willing to listen to your work-related problems?
	Q78.	Are your work achievements appreciated by your immediate superior?

Table 2: Mean (st.dev) of monthly production data for the three firms.

	INPUT		OUTPUT		
Firm1	#Employees	Total Work Hours		Paper Pulp (Tonne)	Pulp Quality Index
2000	380 (1.7)	49,995 (3,741)		27,882 (1,311)	88.2 (2.86)
2001	388 (5.0)	51,302 (4,188)		28,506 (2,010)	91.5 (2.95)
2002	385 (1.9)	51,897 (3,861)		29,718 (4,153)	91.8 (2.89)
2003	383 (3.3)	49,929 (3,407)		32,359 (3,540)	89.5 (3.95)
Firm2	#Employees	Total Work Hours	Fluff Pulp (Tonne)	Paper Pulp (Tonne)	Pulp Quality Index
2000	553 (4.5)	70,734 (7,390)	17,288 (3,236)	25,620 (5,307)	84.7 (14.2)
2001	556 (9.0)	68,396 (7,263)	15,199 (4,476)	23,733 (5,300)	90.3 (4.3)
2002	566 (7.5)	69,336 (6,653)	16,983 (2,700)	24,462 (2,902)	84.9 (10.9)
2003	573 (3.4)	69,387 (6,559)	16,744 (2,464)	25,929 (4,183)	93.1 (2.7)
Firm3		Total Work Hours	Seamless Tubes Warm (Tonne)	Seamless Tubes Cold (Tonne)	Re-work Indicator
2000		124,382 (27,823)	2,535 (662)	790 (172)	.4583 (.1316)
2001		130,042 (27,674)	2,709 (573)	804 (168)	.4411 (.0597)
2002		125,218 (26,951)	2,805 (601)	868 (222)	.5155 (.0636)
2003		129,082 (27,847)	2,373 (557)	954 (228)	.5398 (.1200)

Table 3: The GRM parameters for Health Status.

		Mobility $EQ1$	Self-Care $EQ2$	Usual Activities $EQ3$	Pain $EQ4$	Anxiety/Depression $EQ5$
Firm1	β_0	3.033	2.282	3.343	2.837	.969
	β_2	n/a	n/a	-2.712	-2.313	-4.711
	β_3	-1.768	-2.880	-1.767	-.022	-1.287
Firm2	β_0	2.225	1.835	4.433	3.100	1.151
	β_2	n/a	n/a	-2.272	-2.178	-4.295
	β_3	-1.841	-3.337	-1.531	-.034	-1.077
Firm3	β_0	2.351	2.848	3.672	3.305	1.060
	β_2	n/a	n/a	-2.363	-2.069	-4.090
	β_3	-1.805	-2.609	-1.588	.025	-1.064

Table 4: The GRM parameters for Psychosocial Work-Environment.

		Work Demands				Decision Making Demands			Empowerment		
		$Q12$	$Q13$	$Q14$	$Q15$	$Q17$	$Q19$	$Q22$	$Q84$	$Q85$	$Q86$
Firm1	β_0	2.171	1.363	2.055	2.930	4.051	1.254	1.744	3.086	3.879	2.337
	β_2	-2.553	-4.351	-2.659	-2.440	-1.823	-2.804	-2.032	-1.357	-1.230	-1.512
	β_3	-1.043	-2.664	-1.484	-1.384	-.960	-1.707	-.579	-.490	-.359	-.484
	β_4	.408	-.646	.314	.086	.237	-.179	1.308	.477	.461	.686
	β_5	1.329	.963	1.649	1.248	1.390	1.421	2.562	1.609	1.339	1.833
Firm2	β_0	2.244	1.015	2.454	2.803	3.596	1.085	1.934	3.088	3.228	2.345
	β_2	-2.502	-4.540	-2.439	-2.273	-1.684	-3.170	-1.467	-1.287	-1.149	-1.381
	β_3	-.899	-2.558	-1.106	-1.124	-.814	-2.002	-.465	-.501	-.277	-.376
	β_4	.454	-.179	.419	.362	.411	-.440	1.051	.523	.616	.709
	β_5	1.175	1.196	1.615	1.393	1.667	1.262	2.531	1.597	1.589	1.856
Firm3	β_0	1.860	1.031	1.988	2.887	2.599	.943	2.365	3.193	3.108	2.394
	β_2	-2.615	-4.723	-2.589	-2.161	-1.450	-3.874	-1.122	-1.079	-.979	-1.177
	β_3	-1.103	-2.906	-1.038	-1.219	-.603	-2.258	-.092	-.300	-.156	-.189
	β_4	.335	-.560	.507	.221	.564	-.569	1.098	.675	.740	.839
	β_5	1.137	.810	1.505	1.215	1.894	1.281	2.358	1.720	1.623	1.954

		Fair Leadership			Supportive Leadership		
		$Q89$	$Q90$	$Q91$	$Q73$	$Q75$	$Q78$
Firm1	β_0	2.999	4.467	1.201	3.865	3.761	1.772
	β_2	-1.864	-1.895	-4.367	-1.855	-2.344	-1.971
	β_3	-1.211	-1.330	-3.564	-1.081	-1.540	-.865
	β_4	-.426	-.675	-2.087	-.281	-.711	.638
	β_5	.894	.529	-.532	.754	.234	2.013
Firm2	β_0	2.389	4.412	1.417	5.426	1.310	.944
	β_2	-1.770	-1.861	-4.565	-.765	-2.630	-1.097
	β_3	-1.153	-1.350	-2.801	-.584	-1.881	-0.058
	β_4	-.265	-.565	-1.478	-.435	-1.262	.800
	β_5	1.307	.635	-.271	-.254	-.514	1.839
Firm3	β_0	2.632	4.372	1.001	3.629	4.472	1.553
	β_2	-1.607	-1.779	-5.349	-1.744	-2.119	-1.674
	β_3	-1.057	-1.256	-3.879	-1.048	-1.416	-.565
	β_4	-.158	-.501	-2.089	-.198	-.553	.814
	β_5	1.157	.711	-.428	.812	.446	2.163

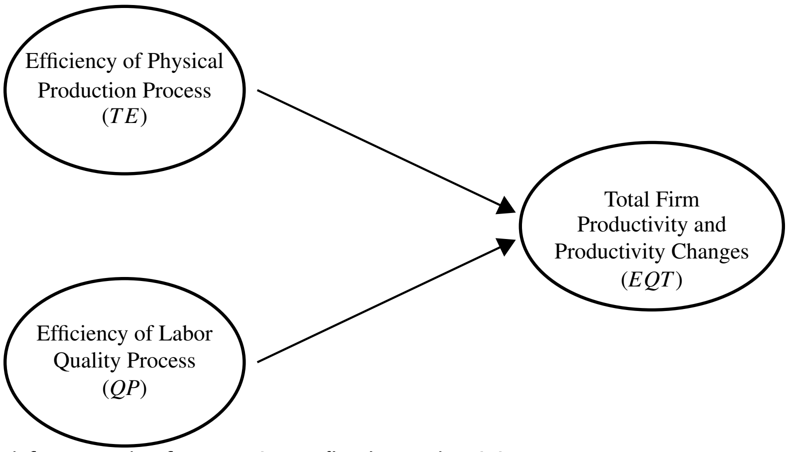


Figure 1: Model framework of measuring a firm's productivity.

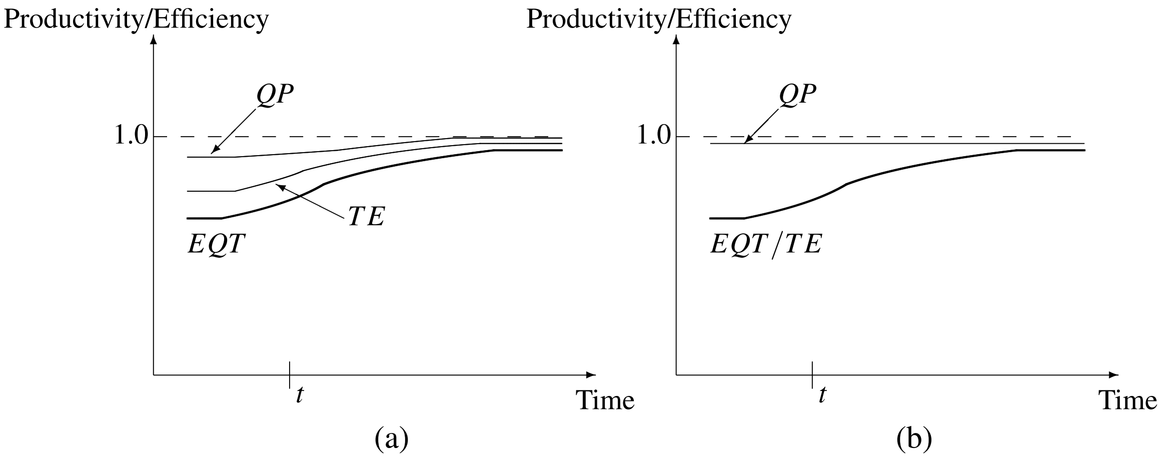
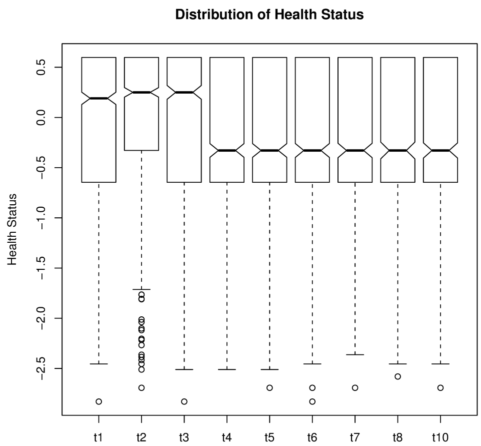


Figure 2: Illustration of overall plant productivity and efficiency of the two sub-processes.

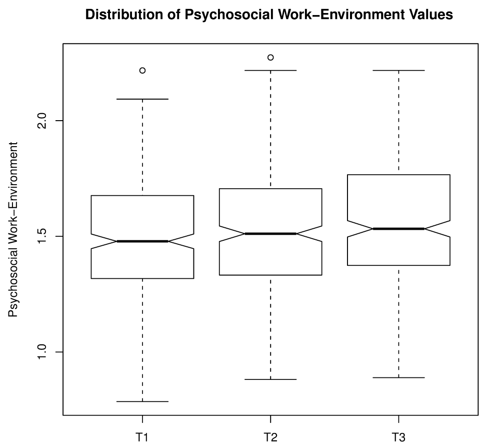
Firm1

Firm2

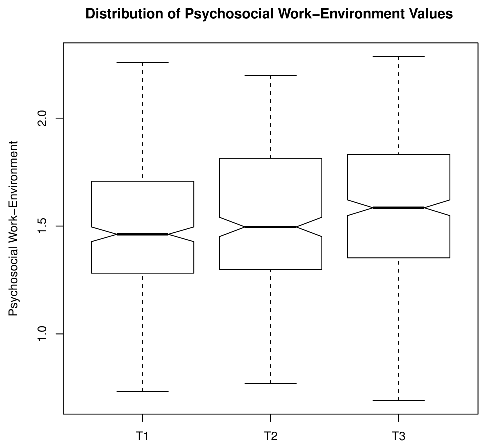


Firm3

Figure 3: Distribution of underlying individual Health Status variable.



Firm1



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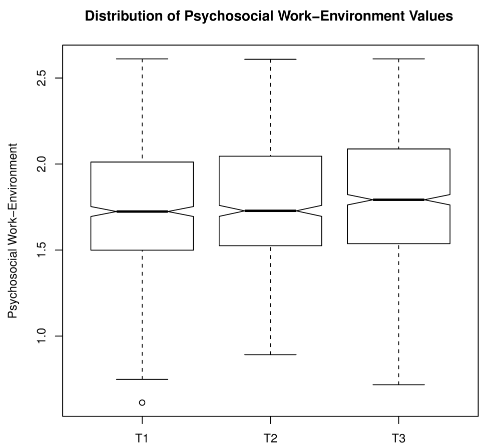
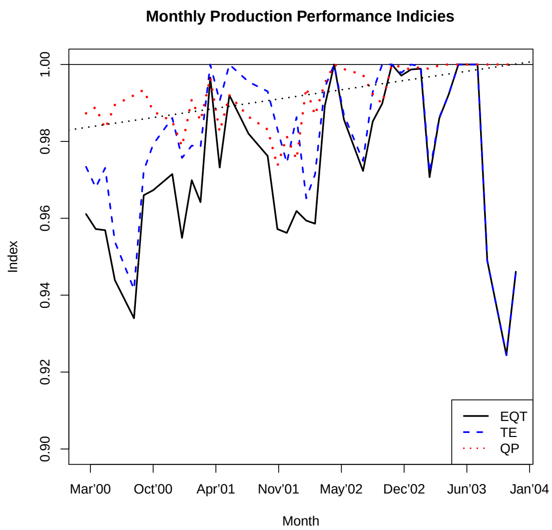
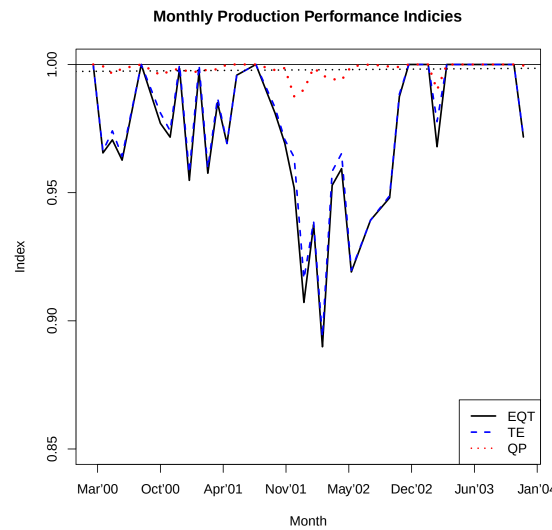


Firm3

Figure 4: Distribution of individual psychosocial work-environment index (MI) values.



Firm1



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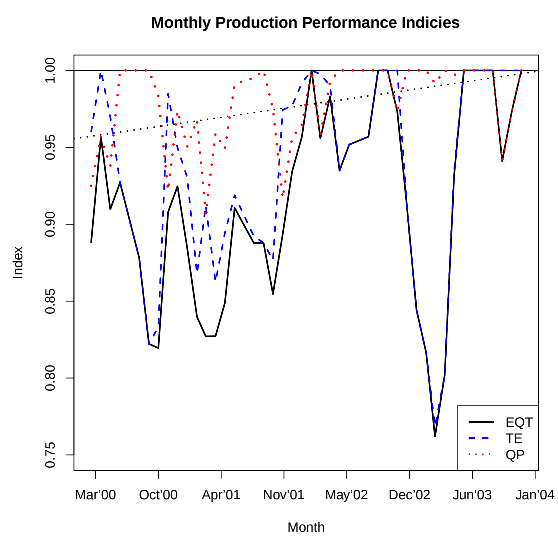

Firm3

Figure 5: Monthly production performance at the three firms.

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