Cost and Productivity Effects of Firm Financed Training[*]

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April 9, 1996

Abstract

A quality-adjusted specification of labor is suggested which allows firm training to affect labor efficiency. To assess the cost and productivity effects, this specification is integrated into a flexible neoclassical cost function. The empirical analysis uses panel data for eight plants in the Swedish Machine Tool Industry. The econometric results imply a high probability that training expenditures result in net decreases in total costs. Judging from the corresponding point estimates, these cost savings can be very large. The estimates of productivity effects are also positive, albeit rather small.

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[*] We have benefited by comments from seminar participants at IUI, Uppsala University, and the Swedish Institute for Social Research at Stockholm University. Harri Kanerva provided efficient research assistance. Financial support from the Working Life Fund is gratefully acknowledged.

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1. Introduction

Recent major technical developments, like the breakthroughs in the field of information technology, have spurred a renewed interest in on-the-job training. Competition induced by the international integration has also led to a growing awareness about the importance of continual skill upgrading. Uncertainty about the effects of such training makes firms cautious in making on-the-job training investments, however.

Research in this area has traditionally focused on individual returns to training, i.e. wage profiles. Very little is known about the costs and benefits accruing to firms that organize training programs.

In this paper we assess how the firm is affected by on-the-job training. Analytically, it is more natural to study the decision-making unit, i.e., the firm, than the participating individuals. In addition, firm effects are important from a social perspective, in particular when public subsidies to on-the-job training are considered.

In the US, state financed workplace-based retraining programs are quite common, cf. Chaplin and Drake (1987), and Creticos and Sheet (1992). In Sweden, a large tax-financed state fund, The Working Life Fund, was set up in 1989 to financially support improvements in the working conditions at the firm level. In order to facilitate organizational changes, a large part of these subsidies was targeted towards retraining programs.

In this paper we develop a formal model to assess cost and productivity effects of firm financed training. The model introduces a quality-adjusted specification of labor in the firm's cost function. The quality-adjusted specification allows firm training to increase labor efficiency and captures the direct effects of on-the-job training. The firm's cost function also accounts for the indirect effects arising through the interactions between labor and other factors of production. In addition, the cost function enables calculation of cost and productivity effects induced by training.

The empirical analysis is based on a unique, plant-level, panel data set which covers eight plants in the Swedish Machine Tool Industry. For these plants, detailed production and cost data are available on an annual basis 1975–93. Since 1989, the data also include information on the firm's training expenditures. Probably due to the limited information on firm training, the precision is low in the parameter estimates associated with quality-adjusted labor. Nevertheless, the estimates imply high probabilities in all firms that training expenditures will result in net decreases in total costs. While imprecise, the point estimates indicate that the cost savings in some firms can be very large. The productivity effects are also found to be positive, albeit rather small.

The paper is organized as follows. In the following section we relate this study to the existing literature. In section 3 the formal model is developed. Section 4 specifies the empirical model and reports the estimation results. Section 5 concludes our findings.

2. Firm Financed On-the-Job Training

In this brief overview of the literature we consider three issues. First, to evaluate the effects of on-the-job training the meaning and content of this concept need to be explored. Second, we discuss some factors determining the amount of on-the-job training carried out. Finally, we consider the modeling framework employed in empirical assessments of firm financed training.

The concept of on-the-job training is broad. Since Becker (1962) and Mincer (1962) the literature has mainly focused on the distinction between general and firm-specific training. Some authors denote as specific any training that, due to transaction costs, cannot be immediately put into profitable use at another firm. Others refer to education provided at the firm's premises as specific.

It is noteworthy that the literature on general versus firm-specific training has shifted focus. Much of the recent research in this area is aimed at providing a rationale for the firm to engage in general rather than specific training. Feuer et al. (1991), for example, dwell on difficulties for the firm to provide a credible contract commitment to future wage increases for employees with only specific training. General training provides the employee with a credible threat point in future renegotiations and thus entice them to stay on longer. Katz and Ziderman (1990) stress that information on the general training provided by one firm is not costlessly available to other firms. Thus, seemingly general training is in fact specific to the providing firm, since poaching firms need to expend considerable resources to confirm its content and quality.

The distinction between general and specific training, is, however, not precise.[1] Nor is it clear what is to be understood by firm training. Different researchers may include in firm training anything from firm financed university courses (Feuer et al., 1991) to experience accumulated in production (learning-by-doing, Killingsworth, 1982) or in problem-solving groups (doing-by-learning, Stern and Benson, 1991). There is also training by external experts, managers, foremen, or col-

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[1] An attempt to make a distinction between different degrees of generality in training can be found in Chaplin and Drake (1987). They classify on-the-job training according to whether it provides college-credit or industry-credit. That is, some of the training provided by the firm merits academic qualification while some is exclusively related to job specifics in the industry. An empirical analysis of the distinction between general versus firm-specific training in Sweden is found in Regnér (1995). In this study there is some evidence that the firms pay for general training.

leagues, formal or informal. In addition, Cadot and Sinclair-Desgagues (1995) argue that not only the employees learn from training; training activities also provide the employer with information on the capabilities of the employee.

It is clear that this diversity of definitions and classifications provides little guidance on how the concept of firm training should be made operational. For empirical purposes it thus seems justified to adopt a pragmatic view and let the available data decide a suitable definition.

What, then, determines the amount of training provided by the firm? First, training requirements will be related to a number of firm-specific factors, for example, the technological level, the organizational structure, etc.[2] Second, an important determinant of training is the rate of technological change. In times of rapid technical progress the need for retraining increases, an argument closely related to the capital embodiment hypothesis and emphasized by Piore (1968, p. 448) as "...the burden of structural adjustment." Empirically, Mincer (1991) confirms this hypothesis.

From a theoretical perspective, an important consideration with respect to the amount of training provided by firms is the possible existence of market failures which could result in underinvestment in training. The market failure argument is treated extensively in a collection of papers edited by Stern and Ritzen (1991). Market failure in training may theoretically exist because of uninsurable uncertainty about the benefits and content of training, complementarity between general and firm-specific training, and interaction with unemployment benefits and transfers. "A special problem with human-capital investment ...; such investments do not create their own collateral..." (Parsons, 1990, p. 64).

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[2] Hashimoto (1991) discusses the fact that Japanese firms spend much more on training than American firms. To explain this finding, he defines a broad concept of training that includes social and communicative abilities to function effectively in teamwork, making very long-term commitments necessary.

This brief discussion of factors determining the amount of training provided by the firm yields several implications for empirical analyses. First, care should be taken to allow for firm-specific effects. Second, the span covered by the data should preferably be long enough to incorporate periods characterized by different rates of technical change. Finally, if possible, it is of interest to test whether subsidies to training have the intended effect of increasing training expenditures or if they merely act as income transfers to firms and individuals.[3]

When it comes to empirical assessments of the effects of firm training the literature is dominated by analyses of individual payoffs, estimated by means of earnings functions in the tradition of Mincer (1974). In a recent empirical study, based on Dutch experiences, it is shown that, on average, individuals that take part in on-the-job training receive 11 percent higher income than those who do not take part in such training (Groot, Hartog, and Oosterbeek, 1994). Moreover, there is some evidence that productivity effects estimated by means of wage changes are downward biased, in that employee productivity sometimes rises much faster than wages, cf. e.g. Bishop (1991), who uses survey assessments of individual productivity, and Barron et al. (1989).

Some attempts have been made to account for the interaction between human capital and other factors of production. Bishop (1991), Bartel and Lichtenberg (1987) and Bartel (1991) do consider interaction with capital but have difficulties distinguishing effects of different factors. In these studies the discussion mainly focuses upon the substitution between labor and capital, thus ignoring possible relationships with other factors of production.

The model to be presented can be seen as an extension of these attempts to account for interactions between labor and other factors of production.

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[3] We do not address this issue in the present paper but we plan to consider it in future work.

3. The Model

Our data enable us to take an approach to the evaluation of firm-sponsored training that is quite different from most previous research. Instead of limiting the attention to the effects on individual's wages the firm is the unit of observation.[4] The firm's cost function is used to assess the effects of firm-sponsored training on costs and productivity.

We start by discussing the firm's labor input. In the following section we consider the firm's cost function. Section 3.3 spells out the input demand equations resulting from the integration of the quality-adjusted specification of labor into the firm's cost function. Finally, in Section 3.4 we show how the impact of quality changes can be calculated.

3.1. A Quality-Adjusted Specification of Labor

The labor input is decomposed into a quantity and a quality dimension, where the former is given by the number of employees and the latter is modeled as a function of, i.a., the amount of resources spent by the firm on the representative employee's on-the-job training.

The labor input, L, can be decomposed according to

$$L = N \times I; \tag{1}$$

where N is the number of employees and I (unknown to us but not to the firm) is an index measuring the quality of the representative employee.

Clearly, (1) specializes to a purely quantitative measure of labor as $I = 1$.

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[4] Hellerstein and Neumark (1995), and Hellerstein, Neumark, Troske (1994) are using a similar approach in that they assess effects of worker characteristics on firm performance. However, their studies do not consider firm financed training and they model the firm's technology in a more restrictive fashion than we do in this paper.

A less obvious property of (1) is that the quality dimension can equivalently be attached to the price of labor, rather than the quantity. This can be seen by considering total labor costs. These can be written

$$P_L L = P_L N I = (P_L I) N = P_N N, \qquad (2)$$

where P_N is defined as total labor costs divided by the number of employees. Indeed, the expression on the far RHS corresponds directly to the way in which the labor input is usually observed: the available data contain information about total labor costs and the number of employees, which together yield P_N. From (2) it follows that P_L can be expressed in terms of the observed cost per employee, i.e. P_N, and the quality index

$$P_L = P_N I^{-1}. \qquad (3)$$

Thus, quality improvements decrease the quality-adjusted price of labor relative to observed average cost per employee.

To model the index I, let variables affecting the quality of the representative worker be comprised in a vector, z. Thus, z contains information about, e.g., the representative employee's human capital and the firm's training expenditures. Data on the firm's R&D expenditures can also be included, since these can affect the firm's stock of human capital.

Since we cannot measure quality in absolute terms we normalize I to unity in some base year. Labor quality is thus measured relative to the base year quality.

On a priori grounds, it is difficult to argue in favor of any particular functional form for the index. For this reason, we employ a first-order (i.e. linear) approximation to the 'true' index, around $I = 1$:

We first note that the true index can be written

$$I = I(z_0) + \left[\frac{\partial I}{\partial z}(z_0)\right](z - z_0) + R \qquad (4)$$

where z_0 is the point around which I is approximated, $I(z_0)$ denotes the index evaluated at z_0, $\frac{\partial I}{\partial z}(z_0)$ the gradient evaluated at z_0, and R the remainder term. To obtain a first-order approximation of I which is equal to unity at the point of expansion we start by setting $R = 0$. We then divide all of the elements in z and z_0 by their base year values, yielding the vectors $\tilde{z}$ and $\tilde{z}_0$. The elements of $\tilde{z}$ will be equal to unity in the base year and the elements of $\tilde{z}_0$ will always be equal to unity, i.e. $\tilde{z}_0 \equiv 1$. Defining, finally, $I(\tilde{z}_0) \equiv 1.0$ and denoting the approximative index $\tilde{I}$ we have

$$\begin{aligned} \tilde{I} &= 1 + \left[\frac{\partial I}{\partial \tilde{z}}(\tilde{z}_0)\right](\tilde{z} - 1) \\ &= 1 + \sum_{h=1}^{H} c_h(\tilde{z}_h - 1) \qquad (5) \end{aligned}$$

where the c_h denote the elements of the gradient vector $\frac{\partial I}{\partial \tilde{z}}(\tilde{z}_0)$. Note that since all $\tilde{z}_h$ are equal to one in the base year, $\tilde{I}$ is by construction equal to unity at this point, as required. The index approximation (5) contains H unknown parameters, $c_h;\ h = 1;\ldots;H$. However, since the values of $\tilde{I}$ are also unknown, the estimation of the c_h requires that we integrate the labor input specification into a comprehensive description of the firm's technology.

3.2. The Firm's Costs of Production

In this paper we have chosen the cost function to represent the firm's technology. A number of cost functions have been suggested to distinguish between short-run and long-run aspects of the production process. This distinction is implemented by allowing some inputs to be quasi-fixed, i.e. fixed in the short run. On a general level, cost functions allowing for quasi-fixed inputs differ with respect to whether they include an explicit specification of the adjustment process to long run equilibrium or whether they merely allow computation of long-run equilibrium solutions. The former class of models are called dynamic cost-of-adjustment models and the latter partial static equilibrium models. For simplicity, we limit our attention to partial static equilibrium models.

We start by considering the firm's variable cost function. In general terms it can be written

$$VC = G(Y; P; X; t); \tag{6}$$

where VC denotes total variable costs, Y the volume of output, P the vector of prices of the variable inputs, and the vector X contains the levels of the quasi-fixed factors. The final argument is a time index representing the state of technology. To implement (6) empirically we have to choose an explicit functional form for G and partition the input set into variable and quasi-fixed inputs.

We chose the Generalized Leontief restricted cost function proposed by Morrison (1988). The notion of capital (K) being quasi-fixed is well established and relatively uncontroversial, but there is less consensus about the possible quasi-fixity of labor (L).[5] In the present context it would seem natural to treat labor as quasi-fixed because employees receiving firm-sponsored training represent an investment for the firm. In addition, for Sweden, in particular, institutional arrangements in the form of active labor market policies and extensive labor market legislation could be expected to dampen the responsiveness in the firm's labor in-

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[5] Japan is a typical example of a country where labor can be treated as quasi-fixed (Morrison (1988, 1992)) whereas US and Canada are more ambiguous cases. For the US and Canada labor is treated as a variable input in Berndt and Hesse (1986) and as a quasi-fixed input in Morrison (op.cit.). To the best of our knowledge, no successful attempt to model labor as quasi-fixed has been reported for Sweden.

put to changes in relative input prices.

The quality-adjusted specification of labor suggested in the previous section requires no presumption about the properties of the labor input. If labor is quasi-fixed, the quality-adjustment can be implemented by means of the quantity equation (1). If labor is treated as a variable input the implementation instead is made by means of the price equation (3).

In the specification reported in section 4 labor is treated as a variable input. For our small panel of plants in the Swedish Machine Tool Industry labor was found to be both highly variable and price sensitive.[6]

In addition to labor, we treat energy (E), and raw materials (R), as variable inputs. To lessen the problem of separating the effects of technical change and returns to scale we impose a constraint of long-run constant returns to scale on the firm's production technology and disregard interaction effects between technical change and short-run returns to scale. This yields the following form of the firm's variable cost function.

$$\begin{aligned} VC \;=\; Y \cdot \Bigg[& \sum_i \sum_j \alpha_{ij} P_i^{\frac{1}{2}} P_j^{\frac{1}{2}} + \gamma_{tt} \sum_i P_i t + \sum_i \delta_{it} P_i t^{\frac{1}{2}} \\ & + \gamma_{KK} \sum_i P_i \left(\frac{K}{Y} \right) + \sum_i \delta_{iK} P_i \left(\frac{K}{Y} \right)^{\frac{1}{2}} \Bigg] \quad i; j = L; E; R. \qquad (7) \end{aligned}$$

The parameters to be estimated are denoted by Greek letters. Implicitly, the price of labor, P_L, is given by equation (3).

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[6] Partially, this can be a statistical artifact because we cannot separate overtime from standard working hours. Although our measure of N is in terms of employees, it is derived from measures of hours worked; data on total wage cost, total number of hours worked, and normal working hours for a full-time employee give the number N of full-time equivalent employees. As argued by Dargay (1987), who also used Swedish data, the number of hours worked per employee is expected to be variable and only the number of employed is expected to be quasi-fixed.

The first term on the RHS of (7) defines the relationships among the variable inputs; if $\alpha_{ij} > 0 \, (< 0)$ for $i \neq j$ then inputs i and j are substitutes (complements). The second term captures neutral technical change, i.e. technical change which affects all inputs in the same way. In contrast, the third term concerns non-neutral, or biased, technical change.

Short-run returns to scale are determined by the fourth and fifth terms. The former captures an input-neutral scale effect. The latter allows for differences across inputs; if $\delta_{iK} < 0 \, (> 0)$ then input i and capital are substitutes (complements) in the sense that an increase in the capital/output-ratio leads to a reduced (increased) demand for input i.

The firm's short run total cost function is obtained by adding the outlays on the quasi-fixed factor to the variable cost function, yielding:

$$TC = VC + P_K K; \tag{8}$$

where P_K denotes the rental price of capital.

We next consider the firm's long-run equilibrium cost function. Firm equilibrium is characterized by the level of the capital stock being such that the firm's total costs are minimized. By the envelope theorem, the optimal capital stock, K^*, is obtained by minimizing (8) with respect to K. Equivalently, K^* is the level of the capital stock at which the shadow-price of capital equals the observed market price, P_K.

The shadow-price of capital, S_K, is given by

$$\begin{aligned} S_K \equiv\ & -\frac{\partial VC}{\partial K} = \\ & -\left[\gamma_{KK} \sum_i P_i + \frac{1}{2} \sum_i \delta_{iK} P_i \left(\gamma_{KK} \sum_i P_i + \frac{1}{2} \sum_i \delta_{iK} P_i \left(\frac{Y}{K} \right)^{\frac{1}{2}} \right)^{\frac{1}{2}} \right]. \end{aligned} \tag{9}$$

By setting the shadow-price of capital equal to the market price we can solve for the optimal capital stock, K^*, which we need later to evaluate long run effects,

$$K^* = K^*(Y, P, t) = Y \cdot \frac{\left[-\left(\frac{1}{2}\sum_i \delta_{iK} P_i\right)\right]^2}{(P_K + \gamma_{KK}\sum_i P_i)^2}. \tag{10}$$

The long-run cost function is obtained by substitution of K^* for K in (8). Thus,

$$TC^* = VC^* + P_K K^*, \tag{11}$$

where VC^* denotes (7) evaluated at K^*. Note that by (10) and (7) the RHS of (11) can be written in the form $Y \cdot \phi(P_L, P_E, P_R, P_K, t)$. This is due to the constraint of long-run returns to scale; marginal costs are equal to average costs.

Before concluding this section we briefly consider the regularity conditions that (7) must satisfy to be a proper representation of the firm's production technology.

With respect to the variable factors, the short-run cost function must be monotonically increasing and concave in the input prices.[7] The monotonicity condition requires that input demands are strictly positive. The concavity condition implies that the matrix of partial (Allen) elasticities of substitution must be negative semidefinite. A simple necessary, but not sufficient, condition is that the own-price elasticities of demand are negative for all variable inputs.

For the quasi-fixed factor, the short-run cost function must be decreasing and convex in the level of K. The first of these conditions is equivalent to the requirement that the shadow price of capital (9) is positive. The convexity condition requires the shadow price to be decreasing in the capital stock. From (9) it can be inferred that a necessary, but not sufficient condition for this property is that

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[7] The cost function should also be linearly homogeneous in input prices. This constraint has been imposed from the outset, however.

at least one of the δ_{ik}'s should be negative, implying that at least one of the variable inputs is a substitute for capital.

3.3. The Quality-Adjusted Input Demand Equations

Differentiating the variable cost function with respect to the prices of the variable factors, i.e., P_L, P_E, and P_R, and using (1) and (3) in the resulting input demand equations, we obtain, by substitution of the approximative index $\tilde{I}$ for the true index I,

$$\begin{aligned}\frac{N}{Y} = {} & \left[\alpha_{LL} + \alpha_{LE}\left(\frac{P_E}{P_N \tilde{I}^{-1}}\right)^{\frac{1}{2}} + \alpha_{LR}\left(\frac{P_R}{P_N \tilde{I}^{-1}}\right)^{\frac{1}{2}} + \delta_{Lt} t^{\frac{1}{2}} + \gamma_{tt} t \right.\\ & \left. + \delta_{LK}\left(\frac{K}{Y}\right)^{\frac{1}{2}} + \gamma_{KK}\left(\frac{K}{Y}\right)\right] \tilde{I}^{-1} \qquad (12)\end{aligned}$$

for labor demand

$$\begin{aligned}\frac{E}{Y} = {} & \alpha_{EE} + \alpha_{LE}\left(\frac{P_N \tilde{I}^{-1}}{P_E}\right)^{\frac{1}{2}} + \alpha_{ER}\left(\frac{P_R}{P_E}\right)^{\frac{1}{2}} + \delta_{Et} t^{\frac{1}{2}} + \gamma_{tt} t \\ & + \delta_{EK}\left(\frac{K}{Y}\right)^{\frac{1}{2}} + \gamma_{KK}\left(\frac{K}{Y}\right) \qquad (13)\end{aligned}$$

for energy demand and

$$\begin{aligned}\frac{R}{Y} = {} & \alpha_{RR} + \alpha_{LR}\left(\frac{P_N \tilde{I}^{-1}}{P_R}\right)^{\frac{1}{2}} + \alpha_{ER}\left(\frac{P_E}{P_R}\right)^{\frac{1}{2}} + \delta_{Rt} t^{\frac{1}{2}} + \gamma_{tt} t \\ & + \delta_{RK}\left(\frac{K}{Y}\right)^{\frac{1}{2}} + \gamma_{KK}\left(\frac{K}{Y}\right) \qquad (14)\end{aligned}$$

for raw materials demand. This is the system of equations to be estimated the empirical analysis. It only remains to specify the variables entering the quality index, according to (5), but this issue will be deferred until Section 4.

The introduction of the quality-adjusted specification of labor alters the standard form of the input/output-equations in two ways. First, in (12) we have exploited the multiplicative relationship between the quantity and quality dimensions of labor to express the LHS of the equation in terms of the quantitative measure of labor that is directly observable, i.e. N. Second, the substitution of $P_N \Gamma^{-1}$ for P_L affects the relative prices involving the price of labor, in all of the three equations.

Thus, while the direct effect of firm financed training can be captured by means of the labor equation, assessment of the indirect effects channeled through the relative input prices requires estimation of all the variable input equations.

3.4. The Impact of Quality Changes

A natural starting point for assessing the effects from firm financed training on the costs of production and on productivity developments is to consider the impact of quality changes in general on these target variables. Starting with the effects on the total costs we have, in the short-run:

$$\frac{\partial TC}{\partial \Gamma} = \frac{\partial VC}{\partial P_L}\frac{\partial P_L}{\partial \Gamma} = L \cdot (-1) P_N \Gamma^{-2} = -\frac{P_N N}{\Gamma}; \tag{15}$$

where the second equality follows from Shephard's lemma and (3), and the last equality is due to (1). Thus, the short-run decrease in total costs induced by a marginal quality improvement is roughly proportional to the wage bill (assuming that the quality index, Γ, does not vary too much over time).[8]

By the envelope theorem, the corresponding long-run effect is given by

$$\frac{\partial TC^*}{\partial \Gamma} = \left.\frac{\partial TC}{\partial \Gamma}\right|_{K=K^*} = -\frac{P_N N^*}{\Gamma}. \tag{16}$$

Accordingly, the long-run impact is simply obtained by evaluating (15) at $K = K^*$.

The evaluation of quality changes on the growth in total factor productivity (TFP) is a considerably more complicated matter. The reason is that the growth in TFP is itself a derived measure. We thus have to start by considering the (dual) expression for the rate of growth in TFP.

As shown by Ohta (1974), total TFP growth can be decomposed according to

$$\frac{dTFP}{TFP} = -\varepsilon_{Ct} \cdot \varepsilon_{CY}^{-1} \tag{17}$$

where

$$\varepsilon_{Ct} \equiv \frac{\partial TC}{\partial t}\frac{1}{TC} \tag{18}$$

and

$$\varepsilon_{CY} \equiv \frac{\partial TC}{\partial Y}\frac{Y}{TC}. \tag{19}$$

The first factor in (17), the negative of the rate of cost diminution, is the dual form of the rate of technical change. The second factor, the inverse of the elasticity of total costs with respect to output, is the dual rate of returns to scale. From (8) and (7) we obtain

$$\varepsilon_{Ct} = \frac{Y}{TC}\left(\gamma_{tt}\sum_i P_i + \frac{1}{2}\sum_i \delta_{it} P_i t^{-\frac{1}{2}}\right); \tag{20}$$

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[8] Since the quality index is normalized (to one in a base year) we do not know how the level of labor quality influences the effect.

$$\epsilon_{CY} = \frac{VC}{TC} - \frac{Y}{TC}\left[\gamma_{KK}\frac{K}{Y}\sum_i P_i + \frac{1}{2}\left(\frac{K}{Y}\right)^{\frac{1}{2}}\sum_i \delta_{iK}P_i\right]. \qquad (21)$$

Using (17) we can express the effect of quality changes on TFP growth as

$$\frac{\partial}{\partial\Gamma}\left(\frac{dTFP}{TFP}\right) = -\left(\frac{\partial\epsilon_{Ct}}{\partial\Gamma}\epsilon_{CY}^{-1} - \epsilon_{Ct}\epsilon_{Cy}^{-2}\frac{\partial\epsilon_{CY}}{\partial\Gamma}\right) \qquad (22)$$

where

$$\frac{\partial\epsilon_{Ct}}{\partial\Gamma} = -\epsilon_{Ct}\frac{\partial TC}{\partial\Gamma}\frac{1}{TC} \qquad (23)$$

and

$$\begin{aligned}\frac{\partial\epsilon_{CY}}{\partial\Gamma} &= \left(\frac{\partial^2 TC}{\partial\Gamma\partial t}Y - \epsilon_{CY}\frac{\partial TC}{\partial\Gamma}\right)\frac{1}{TC}\\ &= \left\{\left[-\frac{1}{\Gamma}\frac{P_N N}{Y} + \left(\gamma_{KK}\frac{K}{Y} + \frac{1}{2}\left(\frac{K}{Y}\right)^{\frac{1}{2}}\delta_{LK}\right)\frac{P_N}{\Gamma^2}\right]Y\right.\\ &\quad \left. - \epsilon_{CY}\frac{\partial TC}{\partial\Gamma}\right\}\frac{1}{TC}.\end{aligned} \qquad (24)$$

Inserting (20), (21), (23), and (24), in (22), and using (15) and (8) thus enables us to compute the short-run effect on TFP growth resulting from quality changes. Fortunately, the long-run effects are computationally simpler.

Since, by construction, there are constant returns to scale in the long run, long-run TFP growth will be equal to the long-run dual rate of technical change, i.e.,

$$\frac{dTFP^*}{TFP^*} = -\epsilon^*_{Ct}. \qquad (25)$$

Furthermore,

$$\epsilon^*_{Ct} = \frac{\partial TC^*}{\partial t}\frac{1}{TC^*} = \frac{\partial TC}{\partial t}\frac{1}{TC^*} = \epsilon_{Ct}\frac{TC}{TC^*}, \qquad (26)$$

where TC^* is given in (11).

The fact that $\partial TC^*/\partial t = \partial TC/\partial t$ also simplifies the calculation of the long-run impact of quality changes on TFP growth since it implies that $\partial^2 TC^*/\partial\Gamma\partial t = \partial^2 TC/\partial\Gamma\partial t$. Thus, in analogy with (22) and (23):

$$\frac{\partial}{\partial\Gamma}\left(\frac{dTFP^*}{TFP^*}\right) = -\frac{\partial\varepsilon^*_{Ct}}{\partial\Gamma} = -\left(\frac{\partial^2 TC}{\partial\Gamma\partial t} - \varepsilon^*_{Ct}\frac{\partial TC^*}{\partial\Gamma}\right)\frac{1}{TC^*} \tag{27}$$

where $\partial^2 TC/\partial\Gamma\partial t$, ε^*_{Ct}, and $\partial TC^*/\partial\Gamma$ are given in (24), (26), and (16), respectively.

Finally, to complete the above formulas we need the driving force behind the quality change. The corresponding partial derivative is simply equal to

$$\frac{\partial\Gamma}{\partial z_h} = c_h. \tag{28}$$

4. The Empirical Analysis

This section begins with a brief discussion of the panel data set used in the empirical analysis. It is followed by a description of the estimated equations, and an account of the way we allow for firm-specific characteristics. The estimation results are then presented. Finally, we report quantitative estimates of the effects of firm financed training on the firms' total costs and productivity.

4.1. The Data

Our panel comprises yearly observations from 1975–93 on eight plants in the Swedish Machine Tool industry. The data are obtained primarily from the Planning Survey, an annual survey administered by the Swedish Federation of Industries and the Industrial Institute for Economic and Social Research, and directed to plants of the 200 largest manufacturing firms in Sweden. In addition, we use some price information provided in the Swedish National Accounts and the Swedish Manufacturing Statistics, both published by the state agency Statistics

Sweden.

The particular plants in our panel are selected for two reasons. They all belong to the same 3-digit level of the Swedish manufacturing industry (SNI 382) and, secondly, they can be followed over a comparatively long period of time. It would be desirable, of course, to enlarge the panel in the cross-section dimension. We chose not to do so, because this either results in a substantial reduction in the time-series dimension, or in an unbalanced panel, which we wanted to avoid for practical reasons.

As mentioned above, our model considers four inputs — labor, energy, raw materials, and capital — and a single output. In addition, it includes a time index, representing technical change. All prices are normalized to unity in 1985 (the base year). The corresponding quantity measures are thus defined in terms of 1985 year cost-volumes. Details on the computation of price indices and cost-volumes for the four inputs and the single output are presented in Appendix I.

The data used to model the quality dimension of the labor input differs from the other time series since it is available only for the period 1989–93. Our quality index depends on two variables. The first is a measure of plant training intensity and is defined as total training expenditure divided by the wage bill, in percent.[9] The training intensities of the eight plants in our panel are given in Table 1. For confidentiality reasons the plants are simply identified by the numbers $1, 2, \ldots, 8.$

It can be seen that while intensities are rather stable within plants, there is considerable variation across plants. For instance, the training intensity in plant number 5 is about six times higher than that in plants number 1 and 4.

Our second quality variable is a measure of R&D intensity. Since R&D, unlike training, is not primarily geared towards any particular factor of production this

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[9] Unfortunately, the data do not allow for a distinction of different types of training. Neither is it possible to control for pre-training differences in human capital stocks across firms.

Plant			Year		
#	1989	1990	1991	1992	1993
1	0.41	0.45	0.72	0.68	0.63
2	3.72	2.03	2.16	1.92	2.43
3	1.14	0.94	0.87	1.10	0.90
4	0.57	0.55	0.56	0.56	0.56
5	3.41	2.99	3.42	3.81	4.35
6	1.67	2.02	1.54	1.92	1.90
7	1.04	1.07	1.73	1.40	1.21
8	0.74	0.74	0.74	0.73	0.73

Table 1: Training intensities, defined as training expenditure divided by the wage bill, in percent. Note: Because of lack of data the 1992 and 1993 values for plant 4 have been extrapolated from 1991 and the 1990 value for plant 8 has been interpolated from the 1989 and 1991 values.

Plant			Year		
#	1989	1990	1991	1992	1993
1	1.25	1.17	1.07	1.09	0.93
2	10.91	12.47	4.78	5.17	3.71
3	6.12	5.10	6.23	5.51	4.77
4	4.31	4.29	4.78	5.26	6.27
5	1.83	1.48	2.92	3.67	3.76
6	0.95	0.79	1.58	1.11	0.75
7	13.51	11.99	13.53	15.75	8.37
8	4.13	5.08	8.41	7.65	5.19

Table 2: R&D intensities, defined as R&D outlays divided by the value of output, in percent.

intensity is defined as R&D outlays divided by the value of output, i.e., total sales plus the change in stocks. Our measure of R&D intensity is closely related to the measures commonly used in the literature on productivity effects of R&D.

With respect to the R&D intensities, the differences between plants are even more marked than for the training intensities; cf. Table 2. In particular, the R&D-intensity for plant number 7 is 10–15 times that of plants 1 and 6.

In general considerably more resources are spent on R&D than on training. This can be seen by comparing Tables 1 and 2. Except for plants 5 and 6, the R&D intensities are much higher than the training intensities, in spite of the fact that the denominators of the former intensities are much larger than those of the latter.[10]

There is no systematic relation between the training and the R&D intensities. In fact, the correlation between the two, across all plants, is only –0.04.

Our treatment of the missing value problem is the simplest possible: for want of better information we have assigned the 1989 values on the training and R&D intensities also to the 1975–88 period observations.

Finally, it should be noted that in the implementation of the quality index, the training and R&D intensities are normalized to unity in the base year 1985. In terms of the notation used in Section 2, the intensities in Table 1 and Table 2 correspond to z_1 and z_2, respectively, whereas the normalized intensities correspond to $\bar{z}_1$ and $\bar{z}_2$. Our treatment of the missing values 1975–88 implies that the quality index will be identically equal to unity 1975–89.

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[10] An important issue is what the firms have recorded as training expenditures. In the Planning Surveys the firms are simply asked to report costs for training which concerns the firm's employees and which has been arranged and financed by the firm. Thus, the firms have not been explicitly asked to include costs incurred in the form of foregone production. For this reason training expenditures may be understated, at least for some firms.

4.2. The Estimated Equations

A central aspect in the formulation of the estimated equations is how to take firm-specific characteristics into account. We chose to model these characteristics deterministically, allowing several parameters to vary across plants. In contrast to the standard approach, we allow for firm-specificity with respect to both intercept and slope coefficients.

However, due to the short time series available for the quality index variables, the parameters are constrained to be equal across plants. Accordingly,

$$\tilde{\Gamma}_{ft} = 1 + c_1(\tilde{z}_{1ft} - 1) + c_2(\tilde{z}_{2ft} - 1) \tag{29}$$

where f indexes firm or, more correctly, plant and t indexes observation period. Still firm heterogeneity is to some extent accounted for in this specification. Since the index is expressed in terms of the normalized intensities, plant differences in the base year values of the intensities are (proportionally) adjusted for.[11]

Concerning the α_{ij}; i.e., the parameters determining the relationships between the variable inputs, collinearity problems forced us to constrain the parameters in the equation corresponding to the smallest input/output-ratio to be equal across plants. Thus, the α_{ij} referring to energy, $\alpha_{LE}; \alpha_{EE}$, and α_{ER}, are common to all plants while the others are firm-specific and thus indexed according to $\alpha_{LLf}; \alpha_{LRf}$, and α_{RRf}.

It remains to discuss the parameters determining (short-run) returns to scale and the effects of technical change. The difficulties to separate these two influences

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[11] To interpret this adjustment, note that (29) can equivalently be formulated in terms of the unnormalized intensities by replacing the second and third terms on the right hand side by $(c_1/z_{1f0})(z_{1ft} - z_{1f0})$ and $(c_2/z_{2f0})(z_{2ft} - z_{2f0})$, respectively, where time index 0 denotes the base year. Thus, using normalized quality index variables is equivalent to assuming that for each plant f the (unnormalized) training and R&D intensities affect the index in inverse proportion to their base-year values, the proportionality constants being equal across firms.

on the firm's costs is a common and well-known problem. In the present context, a natural approach is to restrict some of the associated parameters to be the same for all plants. The scaling properties can then be determined by the cross-section dimension of the panel data set while the technical change effects can be identified by the panel's time series dimension.

The parameters capturing technical change — $\gamma_{tt}; \delta_{Lt}; \delta_{Et}$, and δ_{Rt} — are constrained to be equal across plants and so is one of the scaling parameters, namely γ_{KK}. However, in spite of the fact that we allow the parameters determining the relationships between the variable factors and the fixed capital stock to be firm-specific, we initially encountered problems with frequent violations of the regularity conditions for the capital input. After some experimentation we decided to solve this problem by imposing a level constraint on the equilibrium capital stock K^*. This implies that we capture the variations in the equilibrium capital stock, relative to a benchmark value.

The benchmarks were chosen by means of statistics on capacity utilization in the Swedish manufacturing industry.[12] According to these, capacity utilization reached its highest level during our observation period in 1989. It then fell steadily during the rest of the period. Since the 1989 peak was preceded by several years of steady increases in the level of capacity utilization, a reasonable conjecture is that in 1989 $K = K^*$.[13] Noting that this equality implies that the shadow price of capital, S_K, is equal to the rental price, P_K, one can use equation (9) to impose a constraint on one of the δ_{iK}. We solved for δ_{EK}. Thus, of the four parameters determining returns to scale one is specified to be equal for all plants, γ_{KK}, two are allowed to be firm-specific, δ_{LKf} and δ_{RKf}, and one is specified as a firm-specific

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[12] These statistics were obtained from the private agency Näringslivets Ekonomifakta.

[13] We experimented with different years but that turned out to have only small effects on the estimated parameters.

constant, β_{EKf}.

Adding stochastic disturbances ϵ_{1ft}, ϵ_{2ft}, and ϵ_{3ft}, the estimated equations can be written

$$\left(\frac{N}{Y}\right)_{ft} = \left[\alpha_{LLf} + \alpha_{LE}\left(\frac{P_{Eft}}{P_{Nft}\Gamma_{ft}^{-1}}\right)^{\frac{1}{2}} + \alpha_{LRf}\left(\frac{P_{Rt}}{P_{Nft}\Gamma_{ft}^{-1}}\right)^{\frac{1}{2}} + \beta_{Lt}t^{\frac{1}{2}} + \gamma_{tt}t + \beta_{LKf}\left(\frac{K}{Y}\right)_{ft}^{\frac{1}{2}} + \gamma_{KK}\left(\frac{K}{Y}\right)_{ft}\right]\Gamma_{ft}^{-1} + \varepsilon_{1ft} \qquad (30)$$

for labor

$$\left(\frac{E}{Y}\right)_{ft} = \alpha_{EE} + \alpha_{LE}\left(\frac{P_{Nft}\Gamma_{ft}^{-1}}{P_{Eft}}\right)^{\frac{1}{2}} + \alpha_{ER}\left(\frac{P_{Rt}}{P_{Eft}}\right)^{\frac{1}{2}} + \beta_{Et}t^{\frac{1}{2}} + \gamma_{tt}t + \beta_{EKf}\left(\frac{K}{Y}\right)_{ft}^{\frac{1}{2}} + \gamma_{KK}\left(\frac{K}{Y}\right)_{ft} + \varepsilon_{2ft} \qquad (31)$$

for energy and

$$\left(\frac{R}{Y}\right)_{ft} = \alpha_{RRf} + \alpha_{LRf}\left(\frac{P_{Nft}\Gamma_{ft}^{-1}}{P_{Rt}}\right)^{\frac{1}{2}} + \alpha_{ER}\left(\frac{P_{Eft}}{P_{Rt}}\right)^{\frac{1}{2}} + \beta_{Rt}t^{\frac{1}{2}} + \gamma_{tt}t + \beta_{RKf}\left(\frac{K}{Y}\right)_{ft}^{\frac{1}{2}} + \gamma_{KK}\left(\frac{K}{Y}\right)_{ft} + \varepsilon_{3ft}\ ; \qquad (32)$$

for raw materials and the quality index is given by (29) above.

It should be noted that we also allow plant heterogeneity to be reflected in the variables; as seen from the indices only two of the variables are equal for all plants: the price of raw material, P_R, and the index of technical change, t.

To simplify the estimation, we assume that there are no intertemporal correlations across disturbances. Since all the firm-specific characteristics are assumed to be captured parametrically this means that:

$$E(\varepsilon_{1ft}) = E(\varepsilon_{2ft}) = E(\varepsilon_{3ft}) = 0; \quad \forall f; \forall t$$

$$E(\varepsilon_{dft}\varepsilon_{d'f't'}) = \begin{cases} \sigma_{dd} & \text{if } d = d' \text{ and } t = t' \\ \sigma_{dd'} & \text{if } d \neq d' \text{ and } t = t' \\ 0 & \text{otherwise} \end{cases} \tag{33}$$

where $d = 1; 2; 3$:

4.3. The Estimation Results

To estimate the parameters we used a maximum likelihood procedure. The estimates of the parameters specified in the previous section can be found in Appendix II, Tables 8 to 11.[14]

We first consider the quality index parameters, given in Table 8. The estimate of c_1 is slightly above $0{:}10$. Thus, a marginal increase in the normalized training intensity $\bar{z}_1$ will increase the quality index, as expected, and the increase will be approximately 10 percent. On the other hand, the estimate of c_2 is about $-0{:}07$, i.e., a marginal increase in the normalized R&D intensity $\bar{z}_2$ will decrease the quality index by 7 percent. This finding is less in line with a priori expectations, but not inexplicable. If R&D outlays mainly cover research undertaken outside the plants, and if furthermore firm training and R&D are substitutes with respect to quality improvements in labor, then the R&D intensity might well turn out to be negatively related to quality.

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[14] In addition to these parameters we also estimated coefficients for additive dummy variables, included to account for mergers and splits that affected three of the plants during the observation period. One dummy variable was included in each equation for each of the three plants, yielding altogether nine dummy variable coefficients. These estimates, of which several were significant, are not reported in Appendix II. They are, however, available from the authors on request.

It should be stressed, however, that these interpretations concern point estimates; neither of the estimates of c_1 and c_2 are significantly different from zero. Of course, given the short time series available on the training and R&D intensities it is not very surprising that the precision is low in these estimates.

We next turn to the parameters determining the relationships among the variable inputs, i.e. the α_{ij}: Table 9 shows that almost all of these are significantly different from zero, at the 5 percent level. The negative α_{LE} indicates that labor and energy are substitutes while the positivity of α_{LR} and α_{ER} signifies that raw materials are substitutes for both labor and energy.

Table 10 gives the estimates of the parameters capturing technical change. The input neutral effect, γ_{tt}, is negative as expected, implying a decrease in total cost over time. The estimate is insignificant, however. The positive estimates of δ_{Lt} and δ_{Et} tell that technical change is labor- and energy-using, but these estimates are also insignificantly different from zero. A strong raw-materials-saving bias in technical change is manifested in the estimate of δ_{Rt}, which is significant at the 1 percent level.

Table 11 presents estimates of the parameters characterizing the plants' short-run returns to scale. That the parameter γ_{KK} is positive means that the long-run price elasticity of capital is negative [cf. Morrison (1988, p. 279)], as required by theory, but the parameter is very imprecisely estimated. While the same is true of the δ_{EK} (except for plant 1), the precision is high in the estimates of δ_{LK} and δ_{RK}; the former is significant in six out of eight cases and the latter throughout. The estimates of δ_{LK} are invariably positive, indicating that labor and capital are (long-run) complements. This is quite a common finding in studies based on flexible functional forms, which in contrast to, e.g., the Cobb-Douglas function, does not constrain labor and capital to be substitutes a priori. In the present context, when labor is quality-adjusted, the result also lends support to the capital-skill complementarity hypothesis put forward by Griliches (1969).[15] Raw materials, on the other hand, are found to be substitutes to capital.

An assessment of the overall fit of the estimated equations, per plant, can be found in Table 12. The R_H^2 denote the generalized goodness-of-fit measures suggested by Haessel (1978). These are equal to the squared cosine between the vectors of actual observations on the endogenous variables and the corresponding predictions. By construction, R_H^2 always belongs to the closed interval [0,1]. It can be seen that the fit of the equation for labor is very good for most of the plants. The fit of the energy equation is clearly satisfactory, as well. Only the raw materials equation is poorly supported by the data; for four out of the eight plants R_H^2 is below 0:10:

Durbin-Watson (D-W) measures for each of the equations are also provided in the table. As the statistical properties of the D-W measures are unknown in the present context, the numbers provided can only be viewed as indicative measures. They suggest, however, that autocorrelation might be a problem, at least in the raw material equation where five out of the eight D-W measures are below unity.

Finally, an important consideration is to what extent the regularity conditions stated at the end of Section 3.2 are satisfied by the estimated cost functions. There are very few violations of these conditions. With respect to the variable inputs, the requirement that the cost function be concave in input prices is violated in one plant (19 out of 452 = 8 £ 3 £ 19 observations). The necessary condition of negative own price elasticities of demand holds, however, for this plant at each observation. With respect to the quasi-fixed capital input, the first order condition that the shadow price be positive is violated at altogether five observations out of 152 (8 £ 19). The second-order condition that the cost function is convex in the

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[15] On Swedish data, the capital-skill complementarity hypothesis has been supported in a study by Bergström and Panas (1992).

capital stock is violated at two of the 152 observations.

4.4. Evaluation of the Effects of Firm Training

Table 3 shows the values of the estimated quality indices for the period for which we have data on training and R&D expenditures, i.e., 1989–1993.

As the indices are normalized to unity in the base year 1985 and, moreover, are constant over the period 1975–1989, their 1989 values are equal to one, by construction. Regarding the years 1990–1993, it is clear from the standard errors given below the index numbers that for none of the observations is the index significantly different from unity.

The point estimates, nevertheless, seem quite plausible. Two plants (1 and 7) have indices above unity for the whole period 1990–1993 and equally many (plants 4 and 8) show indices consistently below unity during the same period. In the remaining four plants the quality indices take on values both above and below unity.

In the evaluation of the cost and productivity effects we make a distinction between the short run, characterized by capital being fixed, and the long run in which the capital can be adjusted to its equilibrium level. Here we only report the long run effects.[16] First, the evaluation is performed in terms of elasticities. This has the advantage of making the cost and productivity effects directly comparable. The elasticities do not easily lend themselves to intuitive interpretations, however. Therefore, we also report the "bang for the buck" with respect to training expenditures and the increases in yearly total factor productivity growth rates induced by the training.

Table 4 gives the elasticities in long run total costs with respect to marginal

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[16] Documentation of the short-run effects are available from the authors on request.

Plant	Year				
#	1989	1990	1991	1992	1993
1	1.000	1.015	1.089	1.078	1.072
		(0.011)	(0.076)	(0.066)	(0.057)
2	1.000	0.942	0.998	0.988	1.012
		(0.047)	(0.044)	(0.047)	(0.047)
3	1.000	0.994	0.974	1.004	0.994
		(0.016)	(0.023)	(0.006)	(0.020)
4	1.000	0.996	0.991	0.982	0.966
		(0.004)	(0.007)	(0.014)	(0.028)
5	1.000	1.001	0.957	0.439	0.952
		(0.013)	(0.036)	(0.058)	(0.061)
6	1.000	1.033	0.944	1.003	1.029
		(0.025)	(0.043)	(0.014)	(0.021)
7	1.000	1.012	1.071	1.025	1.045
		(0.009)	(0.064)	(0.032)	(0.032)
8	1.000	0.983	0.924	0.936	0.979
		(0.014)	(0.063)	(0.052)	(0.017)

Table 3: The quality indices 1989-93. Note: Standard errors in parenthesis.

Plant #	1989	1990	1991	1992	1993
1	−0.038	−0.042	−0.054	−0.055	−0.045
2	−0.037	−0.027	−0.027	−0.029	−0.020
3	−0.053	−0.044	−0.043	−0.054	−0.047
4	−0.040	−0.041	−0.040	−0.043	−0.048
5	−0.039	−0.031	−0.037	−0.054	−0.074
6	−0.050	−0.049	−0.049	−0.049	−0.053
7	−0.043	−0.045	−0.049	−0.041	−0.032
8	−0.041	−0.036	−0.044	−0.045	−0.035

Table 4: Elasticities in long run total costs with respect to marginal increases in training intensity.

increases in training intensity, i.e.,

$$\frac{\partial TC^*}{\partial \bar{z}_1}\frac{\bar{z}_1}{TC^*} = \frac{\partial TC^*}{\partial \Gamma}\frac{\partial \Gamma}{\partial \bar{z}_1}\frac{\bar{z}_1}{TC^*} \tag{34}$$

where the first two factors on the right hand side are given by (16) and (28). Notice that since $\bar{z}_1$ is normalized, and thus close to unity, the elasticity will be close to the cost reduction induced by training, divided by total costs.

It can be seen that the cost elasticities are all negative, in accordance with a priori expectations; the average over all plants and all years is equal to -0.043. That is, the average response to a 1 percent increase in the training intensity is a decrease of 0.043 percent in total costs. There is considerable variation, however, both across plants and over time. For instance, the largest entry in the table, -0.074 for plant 5 in 1993, is close to four times as large as the smallest entry, -0.02 for plant 2, also in 1993. Since the computation of variances for these

Plant	Year				
#	1989	1990	1991	1992	1993
1	0.058	0.064	0.085	0.087	0.076
2	0.055	0.040	0.041	0.042	0.036
3	0.074	0.062	0.062	0.077	0.065
4	0.061	0.061	0.062	0.066	0.075
5	0.060	0.050	0.061	0.084	0.103
6	0.072	0.076	0.079	0.083	0.075
7	0.064	0.067	0.084	0.075	0.060
8	0.060	0.061	0.069	0.071	0.058

Table 5: Elasticities in long run total factor productivity growth rates with respect to marginal increases in training intensity.

elasticities is very complicated — even to a first order approximation — we have not made any attempt in this direction.

We next turn to the elasticities in long run total factor productivity growth rates, i.e.,

$$\frac{\partial}{\partial \bar{z}_1}\left(\frac{dTFP^*}{TFP^*}\right) = \frac{\partial}{\partial \tau}\left(\frac{dTFP^*}{TFP^*}\right)\frac{\partial \tau}{\partial \bar{z}_1}\left[\bar{z}_1\left(\frac{dTFP^*}{TFP^*}\right)^{-1}\right]; \qquad (35)$$

where the partial derivative of the TFP growth rate with respect to τ is given by (27). The numerical values of the elasticities are provided in Table 5. As in the case with the cost elasticities, we have not tried to compute approximate standard errors for the point estimates in Table 5; the calculations are even more complex with respect to the productivity elasticities.

Comparison with Table 4 shows that the elasticities in productivity growth rates are somewhat larger in magnitude than the cost elasticities; the overall average is 0.067 and, thus, higher than the absolute value of the average of the cost elasticities. The largest and the smallest numbers in Table 5 are found in the same entries as the corresponding numbers in Table 4, i.e., in 1993 for plants 5 and 2, respectively. Relative to the mean, the variation is about the same as for the cost elasticities.

We also consider two alternative evaluations of the cost and productivity effects that are more easily interpreted than the elasticities. The cost effect will be considered first. The question asked is the following: Assume a marginal increase in firm training expenditure (FTE). How large will the resulting decrease be in long run total costs, per extra SEK spent on training? It can be shown that this ratio is given by

$$\frac{-dTC^*}{dFTE} = \frac{c_1 \cdot 100}{\gamma \cdot z_{10}} \tag{36}$$

where z_{10} is the training intensity in the base year, i.e. the entries in the first column of Table 1.[17] The result is presented in Table 6.

It can be seen that the estimated returns on training expenditures are strikingly large. Indeed, even the lowest returns in the table point to extremely favorable investment opportunities. However, as pointed out in Section 4.1 training costs can be understated to the extent that all plants may not have included cost of foregone production in their training expenditures. If so, the estimates in Table 6 will be biased upwards.

In the table we have also given approximate standard errors and the probabilities that 1 SEK spent on training yields at least 1 SEK in return.[18] From an

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[17] To derive (36), first note that, by (16) and (28), $-dTC^* = (P_N N^*/\gamma)c_1 \cdot d\bar{z}_1$. Next, by definition $\bar{z}_1 \equiv z_1/z_{10}$. Since dividing by z_{10} is merely a normalization we can take z_{10} to be a fixed and given constant. Thus, $d\bar{z}_1 = dz_1/z_{10}$. To expand dz_1 we use the definition $z_1 = (FTE/P_N N) \times 100$. Assuming that $d(P_N N) = 0$ we get $dz_1 = (dFTE/P_N N) \times 100$. Accordingly, $d\bar{z}_1 = (dFTE/P_N N) \times 100/z_{10}$ or, equivalently, $dFTE = (z_{10} \cdot P_N N/100)d\bar{z}_1$. Evaluating $dFTE$ at long run equilibrium, i.e. at $N = N^*$, we get (36).

[18] The standard errors have been computed by means of a first order Taylor expansion of

Plant			Year		
#	1989	1990	1991	1992	1993
1	25.2	24.8	23.1	23.4	23.4
	(23.2)	(22.6)	(19.8)	(20.1)	(20.5)
	0.85	0.85	0.87	0.86	0.86
2	2.80	2.98	2.81	2.84	2.77
	(2.59)	(2.89)	(2.67)	(2.72)	(2.61)
	0.75	0.75	0.75	0.75	0.71
3	9.17	9.23	9.41	9.14	9.22
	(8.46)	(8.63)	(8.91)	(8.44)	(8.66)
	0.83	0.83	0.83	0.83	0.83
4	18.3	18.4	18.5	18.6	18.9
	(16.9)	(17.0)	(17.1)	(17.3)	(17.7)
	0.85	0.85	0.85	0.85	0.85
5	3.06	3.05	3.19	3.26	3.21
	(2.82)	(2.84)	(2.99)	(3.04)	(2.95)
	0.77	0.77	0.77	0.77	0.77
6	6.23	6.03	6.60	6.21	6.05
	(5.75)	(5.43)	(6.24)	(5.66)	(5.48)
	0.82	0.82	0.82	0.82	0.82
7	10.0	9.92	9.38	9.80	9.60
	(9.26)	(9.10)	(8.09)	(8.75)	(8.64)
	0.84	0.84	0.85	0.84	0.84
8	14.1	14.3	15.2	15.0	14.4
	(13.0)	13.3)	(14.4)	(14.2)	(13.4)
	0.84	0.84	0.84	0.84	0.84

Table 6: Returns on marginal training expenditures: long run total cost cost decreases in SEK per SEK increase in training expenditures. In parenthesis standard errors. The probabilities that the returns at least cover costs are italicized.

investor's point of view, these "probabilities of not losing money" should be of primary concern. It is interesting to note that the variation in these probabilities is much smaller than in the estimated returns: for six of the eight plants (plants # 1,2,4,6,7, and 8) the probability of not losing money lies between 0.82 and 0.87.

It might seem somewhat surprising that the probabilities of not losing money are quite high, in spite of the large standard errors in the estimated returns. The principal reason is that these probabilities correspond to one-sided, rather than two-sided tests. An equivalent formulation is that for six of the eight plants the null hypothesis is rejected in favor of the alternative hypothesis $-dTC^*/dFTE > 1$ at significance levels between 13 and 18 percent.[19]

Dividing the probabilities of not losing money, p, by $1 - p$ we obtain the odds for gains vs losses. These odds vary between 6.7:1 for plant 1 in 1991 and 3:1 for plant 2 in 1989–93. For plants 1,2,4,6,7, and 8 the odds are in every year larger than 4.5:1.

The explanation for the very different impressions conveyed by Table 4 and Table 6 lies in the difference between the standards of measurement used in the two cases. In Table 6 we do not relate the induced decrease in total costs to the plant's total costs, as in Table 4, but to the money spent on training.

Finally, we turn to the productivity effects. We assume that training expenditures are increased such that the training intensities increase by 1 percent. Formally, $d(\frac{dTFP}{TFP}) = \frac{\partial}{\partial \Gamma}(\frac{dTFP}{TFP})\frac{\partial \Gamma}{\partial \bar{z}} d\bar{z}_1$, where $d\bar{z}_1 = 0.01 \cdot \bar{z}_1$. The resulting increases in TFP growth rates, in percentage points are shown in Table 7. In parentheses are given the total factor productivity growth rates, in percent, that the increases

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$Var(-dTC^*/dFTE)$ around the point estimates $\hat{c}_1$ and $\hat{c}_2$. The probabilities for not losing money are given by the probabilities $Pr(-dTC^*/dFTE > 1)$. To compute these we have exploited the asymptotic normality of the estimated returns.

[19] A similar result holds for the parameter estimate $\hat{c}_1$: If, in accordance with a priori expectations, we test the null $c_1 \leq 0$ against the alternative $c_1 > 0$ the level of significance is 14 percent.

should be related to.

Measured in this way, the long-run productivity effects appear to be rather modest. The average increase in TFP growth induced by training equals 0.0014 percentage points, which should be compared to the average TFP growth rate, 2.06 percent. To set these numbers in perspective we can calculate what happens over a generation, i.e. 25 years. Without training productivity increases by approximately 67 percent and with training the increase will be about 73 percent, which is not an overly big difference.

The reason why these effects seem so small compared to the effects in Table 5 is that the TFP growth rates are small numbers. Essentially, the difference is that in Table 5 the productivity increases are divided by the TFP growth rates while no such normalization is made in Table 7.[20]

5. Concluding Comments

In this paper we take a first step towards integrating the effects of changes in labor quality into a comprehensive model of the plant. Although we focus on changes induced by firm financed training, our analytical framework can be used for evaluating cost and productivity effects caused by labor quality changes in general. Moreover, the model can easily be adapted to treat labor as a quasi-fixed factor of production rather than as a variable input. In addition to the direct effects on labor, the model also accounts for indirect effects, resulting from the interaction between labor and other factors of production.

In the empirical analysis we have used a small panel data set, covering 8 plants in the Swedish Machine Tool Industry. Unfortunately our time series on

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[20] This simplified description relies on the fact that the training intensities are approximately equal to one. The entries in Table 5 can then be approximated by taking the corresponding entries in Table 7 and divide them by the associated TFP growth rate divided by 100.

Plant	Year				
#	1989	1990	1991	1992	1993
1	.0011	.0012	.0017	.0017	.0015
	(1.90)	(1.93)	(1.96)	(2.00)	(2.00)
2	.0010	.0007	.0007	.0007	.0007
	(1.86)	(1.78)	(1.79)	(1.77)	(1.83)
3	.0015	.0012	.0012	.0015	.0013
	(1.98)	(1.94)	(1.91)	(1.98)	(2.04)
4	.0013	.0013	.0013	.0014	.0016
	(2.07)	(2.11)	(2.14)	(2.17)	(2.10)
5	.0012	.0010	.0012	.0017	.0023
	(2.04)	(2.00)	(2.02)	(2.06)	(2.24)
6	.0017	.0018	.0016	.0019	.0017
	(2.33)	(2.33)	(2.05)	(2.32)	(2.29)
7	.0016	.0017	.0018	.0016	.0013
	(2.48)	(2.45)	(2.15)	(2.07)	(2.11)
8	.0015	.0011	.0014	.0014	.0012
	(2.49)	(1.88)	(1.97)	(1.94)	(1.97)

Table 7: Changes in percentage points, in the rate of long-run total factor productivity (TFP) growth, induced by a 1 percent increase in the training intensity. In parenthesis long-run TFP growth rates, in percent.

firm training expenditures extend over a much shorter period than our cost and production data; 1989–1993 compared to 1975–1993. This may partly explain why the precision is low in our estimates of the quality index parameters.

Our evaluations of the cost effects of firm training are highly suggestive, however. The results imply high probabilities for firm training expenditures to yield long run net decreases in total costs. In six out of eight plants these probabilities are in the interval [0.82, 0.87]. Since a low loss probability should be of primary concern from an investor's point of view, these results are very comforting. Moreover, judging from the corresponding point estimates, it appears that the plants in our sample can make long-run gains in total costs between 3 and 25 SEK per SEK spent on training .

While the productivity effects that we obtain are comparable in magnitude to the cost effects when measured in elasticity terms, the induced additions to the rates of growth in total factor productivity (TFP) are rather modest. Rough calculations indicate that over a 25 year period, the average accumulated growth in TFP will be about 73 percent when the plant engages in training, compared to 67 percent if training is not provided. An explanation for this finding is that whereas cost savings are first-order effects, productivity changes are second-order effects, because productivity growth rates are defined in terms of cost changes. Thus, productivity effects will tend to be smaller than cost effects by construction.

Concerning future research the most important task is to establish whether our results stand when the data are rich enough to enable more precise estimates of the effects. If so, there are important policy implications to consider. More data on training would also make it possible to empirically allow for the fact that the effects of training may extend over several years.

Another obvious extension is to incorporate information on differences across firms in human capital structures. Finally, distinguishing between different types of training, such as initial training and retraining, would also contribute to a more general specification of the labor quality index.

Appendix I: Data

The computation of price indices and cost volumes are presented in some detail in this Appendix. The abbreviations SNA and SMS refer to the Swedish National Accounts and the Swedish Manufacturing Statistics, respectively. Both of these are published by the state agency Statistics Sweden. Throughout, data obtained from these sources refer to the 3-digit sector SNI 382 = Manufacture of Machinery and Equipment in the Swedish manufacturing industry.

Labor

The labor input has a quantity and a quality dimension. The former (N) is measured as the average number of people employed at the plant (full-time equivalents) during the year of observation. In 1993, N varied between 172 and 2452 across the eight plants, with a mean equal to 980, giving a rough indication of the sizes of plants that we are considering. The price corresponding to N, P_N, is simply equal to total wage costs divided by N. Wage costs include payroll taxes.

Energy

Considerable care has been devoted to the construction of the price and quantity variables for energy. Information on usage costs for electricity and fuels is obtained from the Planning survey. For fuels usage costs are equal to expenditures minus stock changes. Energy costs are equal to the sum of the usage costs for electricity and fuels.

To construct an energy price index we have used SMS data on unit costs for electricity and a number of different fuels. First an aggregate unit cost series for fuels has been computed. For each plant in our sample, the relative changes in these two unit costs have then been aggregated by means of the plant's cost shares for electricity and fuels, respectively, in total energy costs.[21] Since these cost shares differ across plants, the resulting energy price indices become firm-specific, in spite of the fact that the underlying unit cost series are the same for all plants. Finally, cost volumes for energy are computed by deflating the plant's energy costs by its energy price index.

Raw Materials

In contrast to the energy price index, the price index for raw materials is the same across plants. The starting point in its construction is a price index for intermedi-

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[21] Specifically, the indices computed are Törnqvist indices, see for example Diewert (1976).

ate goods, obtained from the SNA. Defining this index as encompassing the three goods: raw materials, electricity, and fuels; and using the above mentioned SMS data on electricity and fuel unit costs, we can consistently solve for a price index for raw materials. Finally, to obtain volume measures for raw materials we use the obtained price index to deflate the raw material costs reported in the Planning Survey.

Capital

The Planning Survey data are very rich with respect to the information needed to construct real capital stocks and capital rental prices. There are yearly data on gross investment expenditures for both buildings and structures (B) and equipment and machinery (M). In addition, questions concerning the expected life lengths of newly installed capital have been included in the survey several times. Furthermore, and most important, several attempts have been made to obtain benchmark estimates of the plants' capital stocks by inquiring about the stocks' repurchase or fire insurance value.

From the SNA we have obtained investment price indices for the two types of capital. Finally, end-of-year nominal interest rates on industrial bonds — used in the computation of the capital rental prices — have been obtained from the Monthly Digest of Swedish Statistics.

Given the capital stock benchmarks and the deflated gross investment data, the capital stocks have been computed according to the perpetual inventory method, i.e.

$$K_{f,s,t} = (1 - \delta_{f,s})K_{f,s,t-1} + I_{f,s,t-1}, \quad s = B, M,$$

where index f denotes plant, s the type of capital, and t time period. Gross investment in fixed prices is denoted by I. It should be noted that the rate of depreciation, δ differs across both the type of capital and plant. The depreciation rates have been computed in accordance with Hulten and Wykoff (1981, p. 94), i.e., as the ratio of the declining balance rate over the expected life length

$$\delta_{f,s} = \frac{R_{f,s}}{T_{f,s}}$$

where $R_{f,s}$ and $T_{f,s}$ denote the declining balance rates and the expected life lengths, respectively. Based on studies of the Swedish second-hand markets for machinery and equipment by Hartler (1988) and Asplund (1991) we have set $R_{f,M} = 1.35$ for all plants. For lack of information $R_{f,B} = 1$ for all plants.[22]

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[22] The corresponding numbers used by Hulten and Wykoff (op. cit.) on American data were

The capital rental prices have been computed according to the following discrete time rental price formula suggested by Christensen and Jorgenson (1969) and discussed in Harper, Berndt, and Wood (1989, p. 383):

$$P_{f,s,t} = P^{I}_{s,t-1}\left[r_{t-1} + \delta_{f,s}\frac{(P^{I}_{s,t})^{e}}{P^{I}_{s,t-1}} - \left(\frac{(P^{I}_{s,t})^{e} - P^{I}_{s,t-1}}{P^{I}_{s,t-1}} \right) \right],$$

where $P^{I}_{s,t}$ denotes the investment price index for capital of type s in year t, r_{t-1} the average nominal rate of interest on industrial bonds in December year $t-1$, superindex e denotes expected value. The expected values of the investment price indices have been estimated by means of a Kalman filter procedure.

Aggregate capital stocks have been constructed as follows. For each plant, an aggregate capital rental price has been computed by means of the individual rental prices, $P_{f,B,t}$ and $P_{f,M,t}$, and the capital costs, $P_{f,B,t} \cdot K_{f,B,t}$ and $P_{f,M,t} \cdot K_{f,M,t}$.[23] The aggregate price, $P_{f,t}$ has then been used to deflate total costs to get an aggregate capital stock, $K_{f,t}$.

Output

As mentioned above, the value of (gross) output has been obtained from the Planning Survey as the sum of total sales and changes in the stock-of-trade. To get the volume of output these value measures have been deflated by the SNA producer price index.

1.65 and 0.91, respectively.

[23] Like the aggregate energy prices, these aggregate capital rental prices have been constructed as Törnqvist price indices.

Appendix II: Parameter Estimates and Goodness of Fit Measures

c_1	c_2
0.10419	−0.07321
(0.09611)	(0.06096)

Table 8: The quality index parameters.

Plant #	α_{LL}	α_{LE}	α_{LR}	α_{EE}	α_{ER}	α_{RR}
1	−1.22032**	−0.01864**	0.30200	−0.19373	0.02644**	3.95811**
	(0.37830)	(0.00634)	(0.19074)	(0.34689)	(0.00769)	(0.53223)
2	−0.85201**	– " –	0.04437	– " –	– " –	3.92919**
	(0.36575)		(0.11188)			(0.48763)
3	−1.01317**	– " –	0.72472**	– " –	– " –	2.83746**
	(0.38207)		(0.15507)			(0.52000)
4	−1.50430**	– " –	0.79553**	– " –	– " –	3.17915**
	(0.37766)		(0.12347)			(0.49459)
5	−0.93629*	– " –	0.40178**	– " –	– " –	3.40748**
	(0.36968)		(0.09454)			(0.48918)
6	−1.27075**	– " –	0.56775**	– " –	– " –	3.29903**
	(0.36686)		(0.09333)			(0.48861)
7	−0.79136*	– " –	0.32628*	– " –	– " –	3.46921**
	(0.37159)		(0.13255)			(0.49847)
8	−0.96264*	– " –	0.32740*	– " –	– " –	3.46921*
	(0.38951)		(0.15948)			(0.49773)

Table 9: The α_{ij} parameters. Note: Standard errors in parenthesis. Superindices "*" and "**" denote significant at the 5 percent and 1 percent level, respectively.

γ_{tt}	δ_{Lt}	δ_{Et}	δ_{Rt}
–0.00156	0.07993	0.03463	–0.31324**
(0.00411)	(0.07531)	(0.07529)	(0.08371)

Table 10: Parameters reflecting technical change. Note: Standard errors in parenthesis. Superindices "*" and "**" denote significant at the 5 percent and 1 percent level, respectively.

Plant #	γ_{KK}	δ_{LK}	δ_{EK}	δ_{RK}
1	0.05220	2.53732**	0.09287**	–3.28203**
	(0.08654)	(0.27496)	(0.04754)	(0.28624)
2	– " –	1.93835**	0.00928	–2.50174**
		(0.17252)	(0.04988)	(0.16824)
3	– " –	0.26728	0.02465	–0.93574**
		(0.19764)	(0.05026)	(0.22151)
4	– " –	1.70508**	0.01669	–2.41078**
		(0.11780)	(0.04793)	(0.12646)
5	– " –	0.81528**	–0.00168	–1.49811**
		(0.19027)	(0.04893)	(0.20000)
6	– " –	2.22534**	0.03873	–2.99618**
		(0.23022)	(0.05001)	(0.24981)
7	– " –	0.54425	–0.00155	–1.09133**
		(0.30401)	(0.04962)	(0.32130)
8	– " –	1.05590**	0.02947	–1.70901**
		(0.29313)	(0.04900)	(0.29563)

Table 11: The parameters determining short-run returns to scale. Note: Standard errors in parenthesis. Superindices "*" and "**" denote significant at the 5 percent and 1 percent level, respectively.

Plant	N/Y		E/Y		R/Y	
#	R^2_H	D–W	R^2_H	D-W	R^2_H	D-W
1	0.96	0.45	0.39	0.93	0.11	0.71
2	0.92	1.11	0.54	1.87	0.00	1.30
3	0.82	1.74	0.80	0.97	0.06	0.82
4	0.98	1.02	0.49	1.31	0.04	0.70
5	0.63	1.16	0.41	0.43	0.33	0.86
6	0.93	1.28	0.45	1.17	0.06	0.67
7	0.55	0.92	0.19	0.80	0.23	1.23
8	0.53	1.01	0.25	2.01	0.20	1.23

Table 12: Goodness of fit statistics and Durbin-Watson measures

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