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Productivity with general indices of management and technical change

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HIGHLIGHTS

- We contribute to the nascent literature on the inclusion of observed management into models of production.
- Our general indices models allow technical change to be induced by time and management.
- Time-induced technical change varies with the level of management but the variance over time dominates.
- Management-induced technical change is higher for lower levels of management.

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ABSTRACT

We propose a model of production where technical change is both time and management induced. We define a general management index in addition to the general time index of Baltagi and Griffin (1988) and use them as arguments in the translog production function. Time and management induced technical change are then defined in terms of these general indices. For comparison, we also consider models in which time and management are specified as continuous variables. We report empirical results for a sample of manufacturing firms in the US, UK, Germany and France.

1. Introduction

Business scholars have long maintained that management is an important factor in production. And it is often perceived to be qualitatively different from conventional input factors and attracts special attention. Yet, there is little empirical evidence on how management contributes to production and productivity. To better understand how management affects production we let technical change vary with the level of managerial capability of the firm. That is, we do not only associate technical change with time but also with management.

Empirical modeling of technical change (i.e., the shift in the production function over time) faces a challenge in terms of a trade-off between the flexibility of the production technology and the flexibility with which technical change is characterized (Baltagi and Griffin, 1988; Kumbhakar and Heshmati, 1996; Kumbhakar and Sun, 2012). Index number models (Solow, 1957; Diewert, 1976) allow a fully flexible representation of technical change at the cost of a very restricted model of production (e.g.: constant returns to scale, competitive input and output markets, neutral technical change). Alternatively, econometric models (Tinbergen, 1942; Gollop and Roberts, 1983) offer flexibility for the production technology but require technical change to be a function of time only. In their seminal paper Baltagi and Griffin (1988) overcame this trade-off and introduced an econometric model in which technical change is represented by a general index of time. We generalize their model further by including a management index in addition to the general time index. Just like a general time index model can free technical change from the straitjacket of the time trend, our management index model can free an ordinal variable from the straitjacket of modeling it as a continuous variable. Our

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model allows us to define technical change in terms of a time trend (the traditional one) as well as management (which we call management-induced technical change). This is because the technology (production function in our case) shifts over time as well as with the level of management which is observed in our data.

Our results show that the higher the level of management practice the lower the time-induced technical change. This might seem surprising but we believe there are good (competing) explanations. It is possible that a lower quality of management correlates with more organizational flexibility which in turn makes it easier to exploit opportunities for technical change. Alternatively, well managed firms might already have exploited their potential and therefore have lower technical change. For management-induced technical change we also find evidence (albeit less robust) that technical change is higher for lower levels of management. Again, this might suggest that there are decreasing returns to management.

2. Model

We start from the following specification of the production function

$$y = f\left(x, z, t\right), \tag{1}$$

where y is output, x is a vector of conventional inputs, z is a management variable and t is time trend. Since the management variable is reported on a 1–5 scale we can specify it as either continuous or an index defined from different discrete levels of management. Similarly, time can be treated as a continuous variable or specified as an index from time dummies. These models are known as the time trend and general index models. Since we view management as a shift variable like a time trend, technical change (a measure of the shift in the production function) can be driven by time and/or induced by management. Parametric versions of (1) can be specified in several ways depending on how time and management variables are treated. We alternatively treat technical change and/or management as either continuous or as a general index. That is, the management variable is treated either as continuous (1–5), or we define 5 management dummies $D_m,\ m = 1, \ldots, 5$.

Model 1 (the baseline model): here both management z and time t are treated as continuous variables. The resulting translog form of (1) is

$$\begin{aligned}\ln y_{it} &= \beta_c + \sum_j \beta_j \ln x_{jit} + \frac{1}{2}\sum_j\sum_k \beta_{jk} \ln x_{jit} \ln x_{kit} \\ &\quad + \beta_t t + \frac{1}{2}\beta_{tt} t^2 + \sum_j \beta_{jt} \ln x_{jit} t + \beta_z z_i + \frac{1}{2}\beta_{zz} z_i^2 \\ &\quad + \sum_j \gamma_{jz} \ln x_{jit} z_i + \delta z_i t,\end{aligned} \tag{2}$$

where the subscripts i, t and c represent firm, time and country. The intercept is country specific. Since the management variable in our data is time invariant it does not have a time subscript. However, in general, the z variable is likely to vary in both i and t dimensions.

In Model 1 (time-induced) technical change (TC), which is the derivative of $\ln y_{it}$ with respect to time, is

$$\mathrm{TC}_{1it} = \beta_t + \beta_{tt} t + \sum_j \beta_{jt} \ln x_{jit} + \delta z_i. \tag{3}$$

In a similar fashion, management-induced technical change (MTC) can be defined as the percentage change in output with respect to a change in management, *ceteris paribus*,

$$\mathrm{MTC}_{1it} = \beta_z + \beta_{zz} z_i + \sum_j \gamma_{jz} \ln x_{jit} + \delta t. \tag{4}$$

Model 2: time is continuous but the management variable is an index, defined as $M\left(z_i\right) = \sum_{m=1}^{5} \theta_m D_{mi}$ where θ_m are unknown parameters. The translog form of it is

$$\begin{aligned}\ln y_{it} &= \beta_c + \sum_j \beta_j \ln x_{jit} + \frac{1}{2}\sum_j\sum_k \beta_{jk} \ln x_{jit} \ln x_{kit} \\ &\quad + \beta_t t + \frac{1}{2}\beta_{tt} t^2 + \sum_j \beta_{jt} \ln x_{jit} t + M\left(z_i\right) \\ &\quad + \sum_j \gamma_j \ln x_{jit} M\left(z_i\right) + \delta M\left(z_i\right) t.\end{aligned} \tag{5}$$

Unlike in (2), the management index model in (5) is non-linear because of the interaction terms between inputs and the management index function. Note the difference between this model and a model in which the management dummies appear additively as well as interactively with all other regressors. The latter model is more general and is equivalent to running separate regressions for each level of management which assumes that the production technology differs with the level of management. In the general index model management is treated like any other covariate. The model in (5) is more parsimonious than a dummy model specification, especially when management is constructed from Likert scale variables containing a fairly large number of groups. Technical change in this model is

$$\mathrm{TC}_{2it} = \beta_t + \beta_{tt} t + \sum_j \beta_{jt} \ln x_{jit} + \delta M\left(z_i\right). \tag{6}$$

And management-induced technical change is

$$\mathrm{MTC}_{2it} = \left(M\left(z\right) - M\left(z-1\right)\right)\left(1 + \sum_j \gamma_j \ln x_{jit} + \delta t\right). \tag{7}$$

Compared to (4) this allows the effect of management to be more "erratic" (not smooth). Also factor inputs and the time trend have no impact on management-induced technical change in the absence of pure management-induced technical change. That is there can be no factor bias or scale augmentation in the absence of pure management-induced technical change which is represented by $M\left(z\right) - M\left(z-1\right)$.

Model 3: management is continuous but the time trend in Model 1 is replaced by a time index $A\left(t\right) = \sum_{t=1}^{T} \lambda_t D_t$ à la Baltagi and Griffin (1988)

$$\begin{aligned}\ln y_{it} &= \beta_c + \sum_j \beta_j \ln x_{jit} + \frac{1}{2}\sum_j\sum_k \beta_{jk} \ln x_{jit} \ln x_{kit} \\ &\quad + A(t) + \sum_j \beta_{jt} \ln x_{jit} A(t) + \beta_z z_i + \frac{1}{2}\beta_{zz} z_i^2 \\ &\quad + \sum_j \gamma_{jz} \ln x_{jit} z_i + \delta z_i A(t).\end{aligned} \tag{8}$$

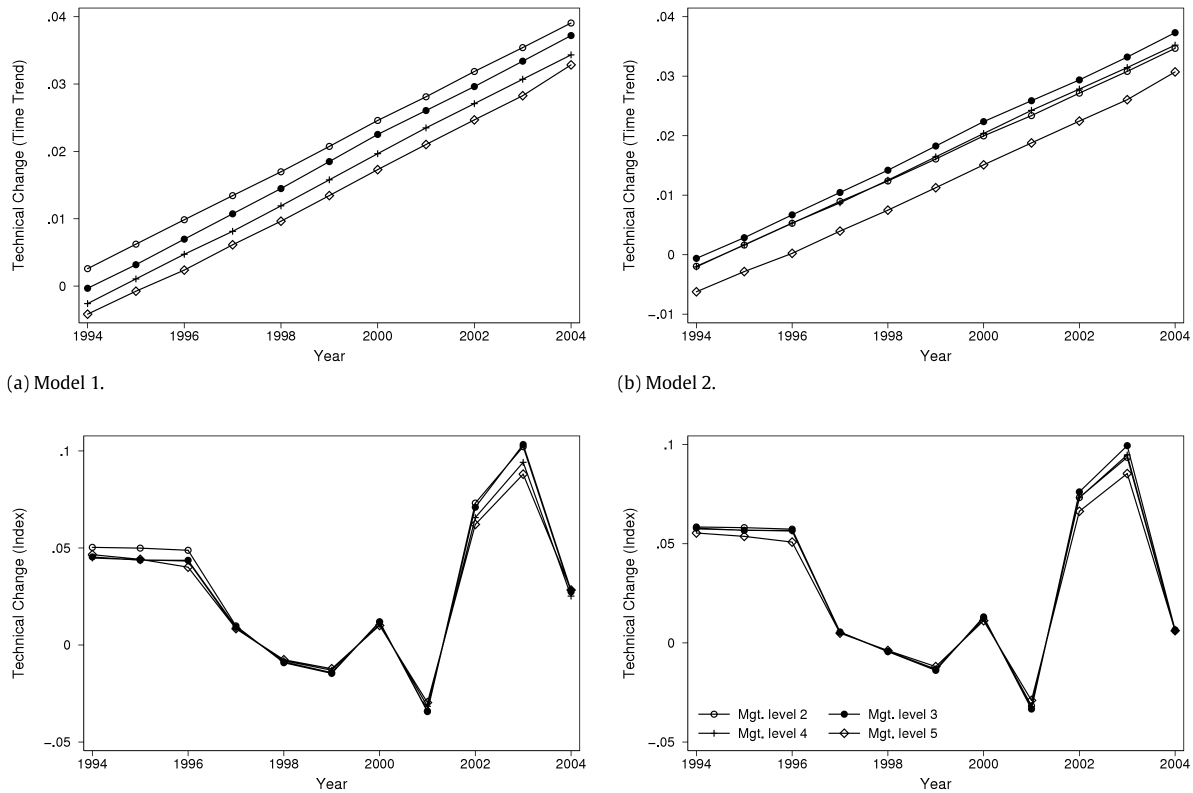
The original motivation for this model stems from Solow (1957) who replaced the time trend in a parametric model by an index $A\left(t\right)$. Baltagi and Griffin (1988) specified $A(t)$ as time-specific dummies. Again, the model in (8) is more parsimonious than a dummy model, especially when T is large (see Baltagi and Griffin, 1988, p. 27, for more on this point).

Technical change in Model 3 is

$$\mathrm{TC}_{3it} = \left(A\left(t\right) - A\left(t-1\right)\right)\left(1 + \sum_j \beta_{jt} \ln x_{jit} + \delta z_i\right), \tag{9}$$

and management-induced technical change is

$$\mathrm{MTC}_{3it} = \beta_z + \beta_{zz} z_i + \sum_j \gamma_{jz} \ln x_{jit} + \delta A\left(t\right). \tag{10}$$



(a) Model 1.

(b) Model 2.

(c) Model 3.

(d) Model 4.

Fig. 1. This figure plots the unweighted firm averages of (time-induced) technical change for different levels of management practice. Management level 1 is the omitted base level.

Finally, Model 4 specifies both management and technical change in terms of indices

$$\begin{aligned}\ln y_{it} &= \beta_c + \sum_j \beta_j \ln x_{jit} + \frac{1}{2}\sum_j \sum_k \beta_{jk} \ln x_{jit} \ln x_{kit} + A(t) \\ &\quad + \sum_j \beta_{jt} \ln x_{jit} A(t) + M(z_i) \\ &\quad + \sum_j \gamma_j \ln x_{jit} M(z_i) + \delta M(z_i) A(t). \qquad (11)\end{aligned}$$

Note that the models in (2), (5), and (8) are nested in (11). Technical change in this model is

$$\mathrm{TC}_{4it} = (A(t) - A(t-1)) \left(1 + \sum_j \beta_{jt} \ln x_{jit} + \delta M(z_i)\right), \qquad (12)$$

and management-induced technical change is

$$\mathrm{MTC}_{4it} = (M(z) - M(z-1)) \left(1 + \sum_j \gamma_j \ln x_{jit} + \delta A(t)\right). \qquad (13)$$

3. Data

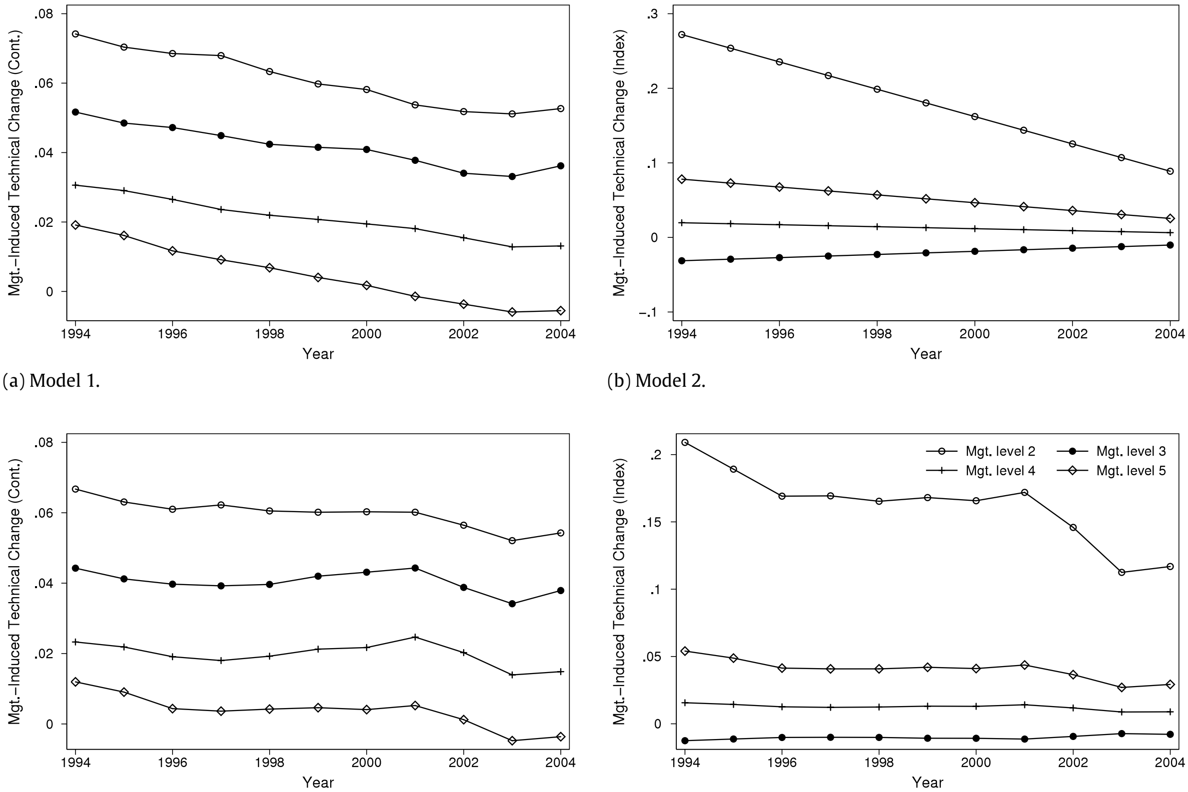
The data is for an unbalanced panel of 505 companies for the years 1994–2004. The total number of observations is 3868. All companies are medium-sized manufacturing firms from the United States, the United Kingdom, Germany, and France. The data was originally collected by Bloom and Van Reenen (2007). Accounting data on these firms were gathered from the Amadeus data base for the European countries and Compustat for the US. The firms were surveyed on their management practices in 2004 using a practice evaluation tool developed in collaboration with a leading international management consulting firm. The tool defines and scores 20 separate management practices or categories. Each practice was scored using several questions. The original responses were given a score from 1 (worst) to 5 (best). Bloom and Van Reenen (2007) use the average across practices as their management variable. Since our general index specification requires discrete values we take the mode across the practices.[1] We measure output as deflated sales net of material input. Capital is measured as tangible fixed assets and labor as employee expenses.

4. Results

We first present results for (time-induced) technical change for each of our four models. Fig. 1 plots the firm averages of technical change by management level; formulas of which are given in (3), (6), (9), and (12). Management level 1 is the base level in the index models and for better comparison we drop it from all model results. In Fig. 1(a) technical change is trending upward for all levels of management but technical change differs in the level of management practice. The level of technical change is not higher for higher levels of management practice. Actually, technical change is strictly higher the lower the level of management practice.

In Fig. 1(b) management is specified as a general index as in (6). The results are similar. But practice level 3 has the highest level of technical change corresponding to an inverse U-shaped relationship between management and technical change.

[1] The scores for individual practices contain non-integer values because they are the averages across several interviewers. Non-integer values represent "disagreement" among different interviewers. After taking the mode we drop all remaining non-integer values (32 per cent of observations).



(a) Model 1.

(b) Model 2.

(c) Model 3.

(d) Model 4.

Fig. 2. This figure plots unweighted firm averages of management-induced technical change for the difference between two adjacent levels of management practice. For example, the line labeled "Mgt. level 2" gives the productivity increase when moving from management level 1–2.

Table 1
This table gives the unweighted firm averages of technical change for different levels of management practice (Model 3).

Year	Management level				Total
	2	3	4	5	
1994	0.050	0.045	0.045	0.047	0.046
1995	0.050	0.044	0.044	0.044	0.045
1996	0.049	0.044	0.043	0.040	0.044
1997	0.010	0.009	0.009	0.008	0.009
1998	−0.009	−0.009	−0.008	−0.008	−0.008
1999	−0.015	−0.014	−0.013	−0.012	−0.013
2000	0.012	0.012	0.011	0.010	0.011
2001	−0.034	−0.034	−0.032	−0.030	−0.032
2002	0.073	0.071	0.066	0.062	0.068
2003	0.102	0.103	0.094	0.088	0.097
2004	0.027	0.028	0.025	0.028	0.027
Total	0.028	0.026	0.025	0.024	0.026

Table 2
This table gives the unweighted firm averages of technical change for different levels of management practice (Model 4).

Year	Management level				Total
	2	3	4	5	
1994	0.058	0.058	0.057	0.055	0.057
1995	0.058	0.057	0.057	0.054	0.057
1996	0.057	0.057	0.056	0.051	0.056
1997	0.005	0.005	0.005	0.005	0.005
1998	−0.004	−0.004	−0.004	−0.004	−0.004
1999	−0.013	−0.014	−0.013	−0.012	−0.013
2000	0.012	0.013	0.012	0.011	0.012
2001	−0.032	−0.033	−0.032	−0.029	−0.032
2002	0.073	0.076	0.073	0.066	0.073
2003	0.094	0.099	0.095	0.085	0.094
2004	0.006	0.007	0.006	0.006	0.006
Total	0.028	0.028	0.028	0.025	0.027

Next, Fig. 1(c) and (d) plot technical change for Model 3 and 4 based on the formulas in (9) and (12), respectively. Unlike Models 1 and 2 technical change is now specified by a general index. Thus, technical change no longer follows a smooth linear trend but fluctuates widely and in particular is negative during the recession around the year 2000. These figures show that when technical change is specified as a general index the variance across time dominates the variance across levels of management. As the scaling does not allow a visual inspection of the effect of management in Fig. 1(c) and (d) we report the underlying numbers for technical change in Tables 1 and 2, respectively. For Model 3 and 4 we see that the gap between the levels of management now varies from year to year. But the qualitative differences in technical change across levels of management is similar to Models 1 and 2, respectively. It seems that removing restrictions on the time trend changes the impact of management on technical change which might be due to a correlation between technical change and management (Baltagi and Griffin, 1988, p. 26).

Now we turn to management-induced technical change, i.e., the productivity change between two levels of management given in (4), (7), (10), and (13). Fig. 2 plots the average management-induced technical change over the years. In Model 1 (Fig. 2(a)), our baseline model, management-induced technical change is strictly decreasing in the level of management. Also, there is a downward trend implying that the marginal productivity decreases when management improves and at a decreasing rate over time. When we ease the restriction on the time trend specification in Model 3 (Fig. 2(c)) we find that the results are similar. However, when looking at the models that specify management as a general index (Fig. 2(b) and (d)) we see that both the ranking across management levels and the time series patterns change. Also, the absolute differences (i.e. vertical distances) between management levels increase. Just like a general index specification increases the variability of technical change over time, the general management index specification also increases the variability of management-induced technical change over the levels of management. With the more flexible management specification it still is the move from management level 1 to 2 that shows the highest management induced-technical change. But the remaining order is different. For instance, the lowest level of management-induced technical change is associated with moving from level 2 to 3. Also, the decrease in management-induced technical change over time is less uniform. The higher the level of technical change the faster is the decrease over time. There is some evidence that better management does not always increase productivity. Similar to other factor inputs the marginal product of management might be decreasing.

5. Conclusion

Just like a general time index model can free technical change from the straitjacket of the time trend, our management index model can free an ordinal variable from the straitjacket of modeling it as a continuous variable. Our general index models allow technical change to be induced by both time and management. For management, as for time, specifying it as a general index increases the variance of the associated technical change. We find that time-induced technical change varies with the level of management. But the effect of time dominates the effect of management. When looking at management-induced technical change we find a decreasing marginal impact of management. Our results contribute to the nascent literature on the inclusion of observed management into models of production.

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