A longitudinal study of the latent class clusters of modern management practices and their association with organizational performance in British manufacturing

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Abstract

In a competitive and global world, lean production as a philosophy that is aimed at eliminating waste and increasing performance is increasingly more attractive. An important question for managers is whether this philosophy implies the integration of human resource management (HRM) and operation management practices (OM). This paper focuses on this integration and investigates the association in use of seven core OM and HRM practices over twenty four years. Based on a large sample of UK manufacturing firms, three latent clusters are identified via ordered restricted latent class models. The cluster that makes a more integrated use of practices outperforms the others. The evolution of the seven practices is captured in latent growth models that describe similar trajectories; this correlation is further explored leading to a classification of firms based on their similarity in history of practice usage. In all, the study provides evidence of a positive link between an integrated managerial approach and performance and that an earlier integration of HRM and OM practices pays off.

Keywords: lean production; performance; latent classes; latent growth and multi-level models.

1. Introduction

During the last decades, as markets have become increasingly more competitive and global, efficiency in getting a product or service to the right place on time is crucial to the survival of any business. In this context, the managerial approach known as lean production became an integral part of the manufacturing environment, possibly due to claims of superior performance and competitive advantage, which have been consistently made by academics and practitioners alike (e.g. Powell, 1995; Mac Duffie, 1995; Wood, Stride, Wall and Clegg, 2004).

Recent papers in the operational management literature (Li, Rao, Ragu-Nathan, Ragu-Nathan, 2005; Shah and Ward, 2007) highlighted the confusion as to what constitutes lean production and consequently how should it be measured. In spite of a lack of consensus, if we consider the history and the spread of operational management (OM) practices in manufacturing, lean production has been commonly taken to involve operational management (OM) techniques concerned with production, work organization, quality management, logistics, supply-chain, customer satisfaction, efficient delivery and continuous improvement methods. In the UK, most of these techniques were pioneered in the early nineties by Japanese subsidiaries, their competitors and suppliers. The adoption of these techniques was still very limited in 1996 (Waterson, Clegg, Bolden, Pepper, Warr and Wall, 1999). But, in subsequent years, a substantial increase in use (about 10%, between 1996 and 2000) was observed. In fact, the increase extended beyond manufacturing and was accompanied by a similar increase in use of human resource management (HRM) practices (Wood et al, 2004).

An important question for managers is whether lean production practices on their own lead to enhanced firm performance, or whether their effectiveness depends on the concurrent adoption of a "people oriented approach" (Wickens, 1995). This is a topic of recent research, which so far has tended to focus on separate practices or specific combinations that are presumed to result in superior performance. The predominant view is that HRM practices, e.g. those which empower or involve the employee, would support specific OM practices and jointly they would have a higher

(nonlinear) effect on performance. In this paper, we contribute to this debate, by addressing the integration in the use of practices that would reflect a managerial philosophy, rather than dealing with practices or specific combinations separately. We examine whether manufacturing firms adopting OM practices that are associated with lean production do so in conjunction with HRM practices (Cooney and Sohal, 2002: 45). We use longitudinal data from four hundred and forty eight UK manufacturing firms (Birdi, Clegg, Patterson, Stride, Wall and Wood, 2008), and, via latent class analysis, we model the association between seven management practices (OM and HRM) as well as their evolution during twenty four years. Having identified homogeneous groups (latent class clusters) of firms, we test the association between group membership and firm performance. In doing so, we assess whether firms in our sample that are likely to integrate key HRM and OM practices outperform those which do not. Furthermore, the longitudinal nature of the data permits modelling the evolution of each practice in the sample, recognising any similarity in growth and investigating whether or not an early integration in the adoption of practices is associated with higher final performance.

In the following sections, we describe the current state of the literature, review the empirical evidence on the link with performance and set out our hypotheses. We then describe the data, the methodology that we use and report our results. Finally, we assess our contribution and conclude.

2. Background and Hypotheses

2.1 The current state of the literature HRM, OM and performance link

Although it has been argued that "putting human resource issues on the top of management's agenda is a prerequisite for the effectiveness of all quality improvement efforts" (Kufidu and Vouzas, 1998: 819), most empirical studies have concentrated on assessing which element of lean production, if any, of just-in-time (JIT), total quality management (TQM), total preventive maintenance (TPM), supply chain partnership or human resource management (HRM) is predominantly associated with firm performance. The key questions have been either whether a

practice is associated with performance or whether sets of practices should be used in conjunction due to their combined effect on performance (synergies). In general these studies have focused on subsets of management practices associated with one or two of the concepts, whose definitions vary depending on the interpretation or the data available to the authors.

In the HRM literature, there is no consensus as how to define constructs. Generally, sets of practices are assumed to be part of a high performance work system (Huselid, 1995; Becker and Gehardt, 1996) and as such presumed to be linked with performance, albeit some negative empirical results (Capelli and Neumark, 2001). Furthermore, key practices like empowerment or work enrichment are often omitted in empirical analyses (Wall and Wood, 2006). Similarly, recent reviews in the OM literature (Nasarinham, Swink and Kim, 2004; Shah and Ward, 2007) also highlighted the confusion regarding the measurement instruments and management practices that are analyzed. For example, Gaither and Frazier (2002) defined lean production in manufacturing as simply JIT repackaged, while Chase, Jacobo and Aquilano (2004) argued for a broader definition. In consequence, analyses of the performance effects of lean production that focus on its multiple components are rare in the operational management field (Shah and Ward, 2003:130).

Part of this perceived confusion stems from the fact that lean production can be treated either as a set of management practices (e.g.: Birdi et al. 2008; Li et al., 2005; Shah and Ward, 2003) or as a philosophy with guiding principles and overarching goals, as portrayed by Womack and Jones (2006) in their description of lean production. The latter implies that OM and HRM practices co-exist due to this philosophy. Accordingly, practices are adopted in an integrated fashion, therefore the adoption or its extent is an indicator of either a factor (latent variable) measuring this philosophy (de Menezes and Wood, 2006), or of a secondary factor thus measuring one of the components of this philosophy (Shah and Ward, 2007). Most empirical studies, however, have dealt with individual practices separately. When combinations were considered, these were due to their expected effects on performance (synergies, moderations and mediations). Few studies were longitudinal, so that as a whole we lack evidence on whether integration between

OM and HRM practices results in superior performance. In order to support our assessment and formulate our study, we now review the empirical evidence.

2.2 The link between modern management practices and performance

Following the dissemination of the TQM philosophy in the US during the eighties, the performance expectations for TQM and related practices have been subject of research. Although the early literature stressed competitive advantage (e.g. Juran, 1993), initial reviews of the evidence reported a lack of association with performance. For example: Reed, Lemak and Montgomery (1996) concluded that any observed benefits were contingent on matching environmental conditions to firm orientation; Powell (1995) did not only identify a reporting bias towards those firms that had effectively implemented TQM (e.g. award winners), but also offered anecdotal examples where the costs of implementing TQM outweighed its benefits.

To this date, many researchers have argued for the potential effects of interactions of practices on performance (synergies). Among these, Flynn, Sakakibara, and Schroeder, R. (1995) claimed that TQM and JIT mutually supported each other, i.e.: TQM reduces process variance, which helps to simplify the manufacturing process and closely match production and customer demand; while JIT affects quality management by reducing lot sizes and thus decreasing the potential waste and rework from process failures. Besides, the combination TQM and JIT, they argued that other practices, which they named infrastructure and are a combination of OM and HRM should interact with either JIT or TQM. Their empirical results based on a sample of US manufacturing plants (n=75) showed strong synergistic effects, especially from combinations that included "infrastructure" practices, among which HRM practices. Consequently, TQM would work best in combination with management support and supplier relationships, while JIT with management support (HRM). The latter effect was also observed by MacDuffie (1995), when analyzing assembly plants in the car industry.

Potential synergies between supply chain and quality management have become topical in the last decade (e.g. Carter and Narasimhan, 1996; Carter, Carter, Monczka, Slaight and Swan,

2000; Mehra and Inman; 2004). The predominant view is that TQM principles expand supply chain management from cooperative relationships aimed at minimizing costs or trade-offs to a focus on achieving cumulative competitive capabilities that target the production of the highest value product for customers. Hence, in an effective supply chain, partners maintain and sustain a customer-driven culture, by offering the right product, in the right place at the right time and at the right price. In order to achieve this effectiveness, a minimum integration of OM practices is required and thus one expects a correlation between the uses of TQM, JIT and supply chain practices. Flynn and Flynn (2005), extended previous work, by actually testing for synergies between TQM and supply chain management, using a larger sample of manufacturing plants from five industrialized countries (n=164). Their TQM measure included JIT delivery and HRM practices and is thus broader than in most studies. Overall, they concluded that TQM supported supply chain management, though not all combinations of practices were positively associated with performance.

Recent studies have focused on the more encompassing concept of lean production and used composite measures of JIT, TQM, and HRM, some of which resulted from factor analysis thus suggesting that practices of the same type co-exist, and assessed the impact of each composite on performance. Shah and Ward's (2003) coverage of the lean production domain is the most comprehensive so far. In contrast to previous work, they used a large sample of American manufacturing plants (n= 1,757) from several industries. Plants were classified into four 'bundles' of related processes and procedures: JIT, TQM, HRM, and TPM. Their hierarchical regression analysis showed that after controlling for industry, union presence, size and age of plant, the adoption of these bundles was positively associated with performance. Each bundle contributed to firm performance, but JIT and TPM contributed more than TQM and HRM. There was no support for the hypothesis that effects are contingent on the chosen controls. Accordingly, Shah and Ward (2003: 145) concluded that 'a separate and identifiable incremental effect can be attributed to the four major lean practices areas'. In comparison to previous work (e.g. Flynn et al, 1995; Powell, 1995), they found a stronger link between OM practices and performance.

In the Operations Management literature, some, like Shah and Ward (2003), have argued that synergistic effects of HRM and OM practices demonstrate an integrated approach to lean production. Nonetheless, few authors have examined integration by modelling the correlation in the adoption of practices. In one of these rare studies, Kaynak (2003) developed a structural equation model of potential effects of HRM and TQM on performance, which was tested on a sample of US manufacturing and service firms (n=42). Three HRM measures were used: management leadership, employee relations, training; plus four quality constructs: quality data and reporting, supplier-quality management, process management, and product/service design. Results supported all paths in the model leading to the conclusion that a range of TQM practices have positive effects on firm performance and thus "practitioners as well as researchers cannot simply pick and choose a few techniques to implement" (p. 427).

More recently, Bou and Beltran (2005) claimed that "the influence of TQM on organizational results will be greater when its implementation is supported by a high-commitment strategy" (p.72) and therefore HRM and TQM should have a synergistic effect on performance. In order to test this hypothesis, in their structural equation model TQM and high commitment management (HRM) are specified as independent latent variables. According to this model, within each type of management the practices are highly correlated (integrated), but there is no correlation between TQM and HRM, which positively interact on performance (Bou and Beltran, 2005: 81, figure 2). Their results, which are based on a sample of 222 service firms, confirm synergy between TQM and HRM. Although they quoted Dwyer (2002:536), by stating that "a model integrating quality and people (practices) could have an impact on the bottom line of the organization", they did not test for integration by assessing whether their two latent variables form a single dimension. That is, by assuming that the correlation between TQM and HRM-centred commitment variable is low or negligible, they contradicted their observation that an "analysis of the foundations of high-commitment management shows clear parallelism with the quality climate proposed by TQM experts, since both approaches (i.e. TQM and high-commitment management) emphasize employee

participation, commitment and trust within the organization" (p. 75). To sum up, this exemplifies the confusion between the *integration* of OM and HRM practices and their potential *synergistic* effect on performance that persists in the literature.

The integration of TQM and HRM practices and its association with performance have been examined in by de Menezes and Wood (2006), who found evidence of integration between TQM and high involvement management practices (HRM), but not with JIT. Their integrated HRM-TQM measure was found to be associated with both productivity and its change.

Given the very limited empirical evidence on the integration of OM and HRM, which follows from the perspective that the coexistence of such practices reflects an overarching philosophy aimed at reducing wastage and increasing performance a kin to the lean production concept (Chandler and McEvoy, 2000; Hart and Schlesinger, 1991; Youndt, Snell, Dean. and Lepak 1996; Shah and Ward, 2007), we test two hypotheses:

Hypothesis 1: Firms using at least one OM practice are more likely to be using at least one HR practice than firms not using any OM practices.

Hypothesis 2: Coexisting HRM and OM practices reflect an integrated managerial approach.

We now turn to the potential link between this managerial approach and performance. In spite of many claims on performance effects, the empirical evidence is still rare. A possible reason for this is that the few studies that adopted this framework were cross-sectional and as such the relationship was analyzed at a single point in time. Hence, it is important that we consider the evidence from longitudinal studies, because they enable the investigation of the associations over time: changes in the dependent variable (performance) as well as the independent variables (e.g. practice use, integrated management approach or lean production) and any effect of these changes in the relationships. Furthermore, they can potentially confirm those associations that were observed in cross-sectional studies. Unfortunately, the evidence from longitudinal studies has been restricted to the direct link between individual management practices and performance and may not be much informative, when we focus on integration. However, we consider two of these longitudinal studies,

Patterson, West and Wall (2002) and Birdi et al. (2008), because they were based on the Institute of Work Psychology (University of Sheffield) Modern Management Practices Survey Series, which led to the dataset that we use here.

The first examined the individual and interactive effects of three OM practices (TQM, JIT and advanced manufacturing technology - AMT) and two HRM practices (job enrichment and skill enhancement) on labour productivity and profit. They found neither support for synergies nor an association between JIT or TQM and performance; only the HRM practices were associated with increases in both productivity and profits. The second extended the above analysis to seven practices: empowerment, extensive training and teamwork, which are central to strategic HRM (Becker and Huselid, 2006); TQM, JIT and AMT, which are the components of integrated manufacturing (Dean and Snell, 1991; Snell and Dean, 1992); and supply-chain partnership that complements the others. The focus remained on separate practices and only empowerment and extensive training were positively associated with performance. Although they observed that associations might be strengthened by teamwork, as a whole their conclusions corroborated with the earlier study: OM practices were not linked to performance, nor was there strong evidence of synergy (the exception was teamwork that interacted with most practices).

In the present study, we revisit this second dataset, but rather than concentrating on individual practices or specific combinations, we focus on the integration of practices. We view lean production as an overarching management philosophy, which implies that an integrated management approach guides the coherent use of OM and HRM practices and therefore we test:

Hypothesis 3: This integrated management approach is positively associated with performance.

2.3 The evolution in adoption of practices and its potential effects on performance

Longitudinal data covering a period that starts in the 1980s enables the study of the evolution of each of the seven practices, assess similarities and describe the sample according to the various stages of adoption. By identifying early adopters, we can further analyze whether early adoption has any sustained effect. . To understand the evolution of practices, we refer to Powell

(1995:20-21) and his use of the diffusion of innovation literature (Rogers, 1983). Accordingly, diffusion of innovation refers to the spread of concepts, technical information and actual practices within a social system. The spread denotes a flow or movement from a source to an adopter, typically by communication or influence. Diffusion trajectories as a function of time are such that at the beginning adoption takes longer and growth is barely observed, then there is a period of growth and finally there is a plateau. This pattern of evolution or growth curve is observed and modelled in many areas, as described in Wejnert's (2002) review of diffusion processes, inclusive in management where the spread of specific HR practices has been recently investigated (Freitas, 2008).

It has been recognised that the similarity between innovators and potential adopters is crucial to the spread (Wejnert's, 2002). Hence, innovations and likewise modern management practices propagate more rapidly among firms that share similar visions, values, approaches and, indeed, a philosophy. In this context, it is plausible that firms, which share philosophies or management approaches, follow similar trajectories in practice use. We therefore consider whether the correlation between the seven trajectories that describe the evolution of each practice in is due to a common factor. If this is the case, this factor would describe the evolution (or different stages) of the integrated management approach that is manifested through the adoption of the practices. Hence, we hypothesize:

Hypothesis 4: The similarity in the evolution of practices is due to a common factor.

Early advocates of TQM argued that any quality strategy should be geared towards improved performance and consequently the earlier the implementation the quicker the gains. Few studies investigated this claim, among these, Easton and Jarrell (1998) developed an event-history study on the impact of TQM between 1981 and 1991. The implementation of TQM was judged according to the Baldridge Award criteria, in which case, an advanced implementation would combine OM and HRM practices. Each firm's performance (accounting and stock returns) was compared with a control benchmark, which captured what performance would have been without

TQM and matched the sampled firm on industry, age, projected performance (and, whenever possible on market size, debt-to-equity ratios and a market risk factor). Independently of the performance measure, a positive link with TQM was established and the observed improvement in performance was larger three to five years after TQM implementation, thus leading the authors to support the view of a longer term impact. Recent work, however, suggests that expectations of sustainable effects might have been too optimistic. For example, Hendriks and Singhal (2001) found no significant difference in performance between earlier and later "effective" implementers (award winners) of TQM and argued that the positive effects of TQM could be diluted by other factors within the organization.

All in all, we lack coherent evidence on any link between the evolution of management practices and firm performance and, as far as we are aware, longitudinal studies of practices associated with lean production have not focused on them as an integrated package. We therefore explore this gap by addressing two questions, which will give us additional insights into the potential benefits of integrated managerial systems, namely:

1. Is there an association between the overall evolution of practices and performance?
2. If so, do early adopters outperform others?

We note that a potential long term effect of an integrated management approach could deter its diffusion, because only firms that have higher investment capacity would be willing to adopt a practice and wait for medium or long-range returns. In which case, integration would be biased towards high-performers and thus we would expect early adopters to be high performers.

The diffusion process and consequently the link with performance can be highly influenced by learning effects, which may create asymmetries among firms and deter the spread of adoption. In fact, when practices are viewed in bundles, learning can be subject to considerable variance, some features can be easily transferable others may suffer greater resistance, and therefore a long-range investment can be perceived as too risky. Innovators would then be those who are willing to take the risk and their investment in continuous learning would create a gap between them and the

others. Early-adopters would then benefit from the sustainable learning that is associated with the lean production concept. In contrast, if there are spillover effects (e.g. due to the spread of technology) diffusion can be faster, since firms can easily jump into the learning curve and benefit from having an integrated approach to management. In this context, if learning is not cumulative, any initial advantage may quickly dilute as the innovation spreads. In short, we have no clear expectation as to whether or not there should be an association between the evolution of this set of practices and performance, or if there are sustainable effects. By addressing the above questions, we aim to achieve a clearer picture of what went on in British manufacturing with regards to integrating key OM and HRM practices during a period when there was significant increase in the adoption of each of these practices.

3. The Empirical Study

3.1 The Data

We refer to the Institute of Work Psychology (University of Sheffield) Modern Management Practices Survey Series (Birdi et al.,2008) for the data on seven practices that are the most extensively used in British manufacturing (Wood et al, 2004) and records of company performance for the period 1980-2003. The OM practices are: total quality management (TQM), just-in-time procedures (JIT), integrated computer-based technology (ICT, also known as advanced manufacturing technology) and supply-chain partnering. The first three are central to any integrated manufacturing system and the last adds the custom-supplier relationships that are necessary for the delivery of desired standards at a minimum cost. The HRM practices are: learning-culture or extensive training, empowerment and teamwork. The first two have been consistently associated with quality management, as shown by the criteria of the 1992 Balridge award (George, 1992) and two of Deming's fourteen points (Walton, 1986). Team-work is core to the high involvement concept (Bailey, 1993; de Menezes and Wood, 2006). Together we would expect these practices to

allow employees to enhance their knowledge of the company, work more flexibly and thus take more responsibility for its operational management.

The usage of each practice in each year of the study was recorded as a binary indicator (1 if a firm was using a practice that year, otherwise 0). Productivity, which is our dependent variable, was measured as the logarithm of value added derived profit and loss (operating profit, labour costs and depreciation), adjusted for GDP inflation so that the measure is standardised to 2001 prices.

In all, 684 UK manufacturing organizations provided information on their use of four OM and three HRM practices, via structured interview and questionnaire. Out of these, 448 had observations for all seven practices in every year of our study period, and 308 had financial data as well as some information on management practices. All company-related data are from the annual audited accounts held at Companies House in London, where checks were done and any anomalies were corrected prior to the creation of the dataset (Birdi et al, 2008). Nevertheless, 157 companies had both complete information on all seven practices and performance data, which are unavailable for the first two years in the dataset. Following preliminary analysis that we describe in the next section, our hypotheses on the integration of practices and the evolution of practice-use are tested on a sample size of 448, but when addressing the association with performance we are limited to the smaller sample (n = 157) and the period from 1982 to 2003. Yet, our sample size is comparatively larger than other studies in the manufacturing industry that relied on data selected from larger populations (e.g. Flynn et al. 1995; Kaynak, 2003; Powell, 1995).

In the first part of our study, when considering the yearly association between the management approach and performance, the models are controlled for: size of workforce (log number of employees); value of assets (log fixed assets adjusted for inflation); time (accounting year). In the second part, when examining the association between practice evolution and early adoption with performance, we add initial performance to our controls, and measure time by the number of years from the starting accounting year.

3.2 Analysis Procedure

We first assess whether there is co-existence in the use of practices via Chi-square tests. If practices were used independently, we would have no grounds to either pursue the analysis of practices as an integrated package or to believe that a managerial philosophy was responsible for the choice of practices. Having observed that there is association, we can then examine the association between HRM and OM practices and test whether there are grounds to expect an integrated use of these two types of practice. In order to test hypothesis 1, we created two binary variables that indicate for each year whether a firm adopted at least one OM practice and whether they adopted at least one HRM practice. If these variables are associated, we conclude that there is ground for integration between HRM and OM practices in the sample.

Having established that there is significant correlation in practice use, we can test for each year whether this correlation is due to a single factor. Since our yearly data consists of binary variables that indicate the use of each of the seven practices, we fit a latent trait model, as proposed by Bartholomew and Knott (1999) and used by de Menezes and Wood (2006) in their analysis of management practices. In doing so, we determine whether the variables load into a single continuous dimension. For brevity, we report that these fits were poor and from now on we consider a categorical latent variable or the latent classes, as initially proposed by Lazarsfeld and Henry (1968).

According to this standard latent class model, we assume that binary indicator variables are associated due to discrete points (or classes) in the latent space. We also let π_{ij} be the probability of the i^{th} practice being used by a firm in category j, η_j be the prior probability that a randomly chosen firm is in class j, and $\mathbf{x} = (x_1, x_2, \ldots, x_7)$ represent the response of a firm to the use of these 7 practices. As we only observe $\mathbf{x}$, inference must be based on the joint distribution, whose density for the K-class model is given by:

$$f(\mathbf{x}) = \sum_{j=1}^{K} \eta_j \prod_{i=1}^{p} \pi_{ij}^{x_i} (1 - \pi_{ij}^{x_i})^{1-x_i} \qquad (1)$$

The posterior probability that a firm with response vector $\mathbf{x}$ is in class j is therefore:

$$h(j|\mathbf{x}) = \frac{\eta_j \prod_{i=1}^{p} \pi_{ij}^{x_i} (1-\pi_{ij})^{1-x_i}}{f(\mathbf{x})},\ j = 1,\ldots K \qquad (2)$$

Firms are then allocated into the classes for which this probability (2) is the highest. All parameters are estimate by maximum likelihood. A loglinear reformulation of this model, whose parameters are no more probabilities and as such not restricted to the interval [0,1], enables linear restrictions to be applied to the parameters and more flexible inference (Heinen, 1996; Vermunt, 1999).

On identifying yearly latent class clusters and testing their link with Performance

Latent Class models are here used to identify homogeneous groups of firms (latent class clusters) based on the co-existence of practices in the sample. In doing so, we assume that a discrete latent variable is responsible for the association in practice-use. If it were not the case, we would not be able to fit a latent class model to the data. As a matter of fact, this method is consistent with viewing the relationships among the elements of lean production as neither explicit nor precise in terms of linearity or causality (Shah and Ward, 2007:791). Our models assume that in the absence of a managerial philosophy (lean production) practices are used independently and estimate the likelihood of a firm belonging to a cluster as well as its probability of adopting a practice. Consequently, in a cluster we have firms which do not necessarily make use of exactly the same subset of practices, but by having the same likelihood of adopting each practice, they have a similar approach to management. In summary, we adopt a statistical model-based clustering approach that, in contrast to standard cluster analysis, enables parameters to be restricted and the use of formal tests to check for its validity.

LatentGold 4.0 (Vermunt and Madigson, 2005) is used to estimate the parameters in each model and to provide the goodness-of-fit and model selection statistics, which we use to determine the number of latent class clusters. By maximising the log-likelihood function, the probabilities that a company uses a practice given that it belongs to each cluster (π_{ij}), the size of each cluster (η_j) and the posterior probability that a firm would belong to a cluster (2) are estimated. A firm is then allocated to the cluster which it has the highest (posterior) probability of belonging to. In which

case, although each firm is assumed to belong to one class or cluster, the uncertainty in membership is taken into consideration. We note that multiple sets of random starting values avoid local solutions and that we check bivariate residuals in order to detect any dependency between pairs of practices, which, if necessary, can be modelled.

Although the original data was used by Birdi et al. (2008), we do not focus on the same subset, since their analysis excluded data from two years that lacked information on performance. Furthermore, they focused on either separate practices or specific interactions of smaller subsets of practices, so their sample sizes varied depending on the amount of observed information. Given seven practices, there are 128 possible combinations of practices that we could observe in the data. A latent class model aims at fitting all these possible patterns. Hence, we started with as much information as possible on practice usage to fit different latent class models. We fitted the standard unrestricted model, which we described, and investigated the evolution of groupings and the numbers of clusters that best fit the data in each year. We observed that the results, which excluded missing values practice by practice, were inconsistent over the years. Hence, in subsequent latent class analyses, we restrict the sample to those firms that have complete information on practice use for every year (sample size = 448). We fit up to five latent classes per year and, as we describe in the next section, the best solutions imply either two or three-classes. However, the yearly classification varies and we thus ordered them, by estimating order-restricted three-latent class models (Goodman, 1974; Croon, 1990). In which case, the probability of a firm using a practice changes monotonically as we move along the sequence of classes ($\pi_{ij} \geq \pi_{ij-1}$). A model with ordered classes represents an intermediate stage between the latent trait model, in which the latent space is a continuum like in factor analysis, and the standard latent class model that, as described above, assumes a categorical latent variable.

In each year a firm is then allocated to the latent class cluster that, according to the model, it is most likely to belong. This procedure results in three ordered homogeneous clusters of firms per year: low-usage (Cluster1), medium-usage (Cluster2) and high-usage (Cluster3), in each cluster the

probabilities of a firm adopting a practice *j*, where *j*=1 to 7, is the same. Cluster sizes are also estimated and vary from year to year, as we will see in the next section.

The association between cluster-membership and performance is investigated via a two-level hierarchical regression procedure, using Mixed Models with SPSS14. The first level is time (*t*) and the second is the company (*i*). The medium-usage cluster is chosen as the baseline, so that we would expect a positive coefficient for Cluster 3 and/or a negative coefficient for Cluster1. Our model is the following:

$$Performance_{it} = \beta_s Size_{it} + \beta_A Assets_{it} + \beta_T T + \beta_{Cl1} Cluster1_{it} + \beta_{Cl3} Cluster3_{it} + e_{it} \quad (3)$$

where: $Cluster1_{it}$ is 1 if firm *i* is low-usage at time *t*, and 0 otherwise; $Cluster3_{it}$ is 1 if firm *i* is high-usage at time *t*, and 0 otherwise; and e_{it} is the error term. Time (*T*) varies from 1982 to 2003, but is rescaled so that it starts in 1982 (the first year for which performance data is available). The correlation structure of the first level residuals is identified and estimated from a baseline model that excludes the cluster membership predictors. Improvement in model fit between the model described in equation (3) and the baseline model is determined by the change in -2 times the log-likelihood, which is a likelihood ratio statistic that in our case is distributed as a Chi-square with two degrees of freedom (due to two additional parameters relative to the baseline model).

On identifying patterns in the evolution of practice-use and assessing their association with performance

In order to establish the trajectory (evolution) of each practice, we estimate latent growth cluster models, as described by Vermunt and Madigson (2005), for each individual practice and then use these clusters to classify each firm according to the identified trajectories in practice use. This is a two-stage process that leads to a single classification of firms based on the diffusion of practices over the twenty-four years.

In the first stage, we examine the growth pattern of each practice separately. The aim is to find the best model (correct number of latent classes) for each practice. However, after attempting to model the growth using the 24 points in time, we did not arrive at unique solutions. Therefore,

we divided the period 1980-2003 into five epochs as follows: epoch 0 = 1980-1984; epoch 1 = 1985-1988; epoch 2 = 1990-1994; epoch 3 =1995-1999; epoch 4 =2000-2003. If a practice was introduced at any time during an epoch, or was already in use at the beginning of an epoch, the practice code for that epoch was set to 1. Otherwise the practice code for that epoch was 0.

We first estimate latent growth cluster models for each of the seven practices, and then use the identified clusters as inputs to a second level classification (the 'trajectory class') that summarizes the overall evolution of the adoption of practices. Finally, we investigate whether this second level classification is associated with firm performance, by examining value-add in the last available accounting year as a function of trajectory class. A General Linear Model is estimated using SPSS14, where the dependent variable is final performance, the covariates are: initial performance, final company size, final fixed assets and accounting period. The trajectory class is the categorical predictor.

4. Empirical Results

4.1 On the yearly integration of practices

If we had no evidence of co-existence amongst practices, we would not be able to fit any latent variable model to the data and thus hypotheses 1 and 2 would be immediately rejected. Thus we first considered whether HRM and OM practices were used independently in the period studied.

In 1980, 14% of firms reported using one or more OM practices and only 9% reported using one or more HRM practices; by 2002 these figures had grown to 99% and 98% respectively. In order to see whether HRM practices were adopted independently of OM practices, we created two binary indicator variables. For each year, the first variable indicated whether a firm had adopted at least one OM practice and the second whether a firm had adopted at least one HRM practice. Cross-tabulation of these two variables suggested that in every year prior to 2002, firms that had adopted at least one OM practice were more likely to be using at least one HRM practice than firms that had not adopted any OM practices. With the exception of 2002 and 2003, by which time almost all

firms had adopted at least one OM and one HRM practice, chi-square tests of independence with continuity correction were strongly significant ($p \leq .002$) for all years. This indicates that HRM and OM practices have a tendency to be used together. There is no evidence that firms emphasized either OM or HRM practices or that separate clusters of each type of practices are likely to emerge from these data. Hypothesis 1 is thus supported and we have grounds to test hypotheses 2 and 3.

Identifying homogeneous groups of firms in each year (1980-2003)

We initially considered up to five latent classes. However, some models resulted in multiple solutions, possibly due to our sample sizes, which were not large enough to capture patterns in the data that would stem from larger models. Furthermore, our dataset is also sparse in the sense that many of the 128 possible patterns of responses are not observed in the samples. We therefore estimated 2 and 3 latent class models (up to 23 parameters in a model) in each year, and checked which best represented the data. The log-likelihood based model selection criteria (AIC, BIC, CAIC) suggested a three cluster (latent class) solution in some years and a two cluster solution in others. This is illustrated in the plot of the Akaike Information Criterion (AIC) that is shown in figure 1: the smaller the AIC statistic, the better is the model.

Figure 1

It can be seen, in the first decade of the period, that two and three latent cluster solutions fit the data equally well. From about 1990, however, three cluster solutions fit better and, towards the end of the period, the quality of fit of the two and three cluster solutions begins to converge again. It appears that the pattern of co-existence of practices evolves in the period investigated. The classification oscillated between years, in the sense that the ordering of clusters varied, and we concluded that in order to achieve consistency year to year, order-restricted models are required.

Although the three-class solution would be worse than the two-class solution in a few years, using a three-class model throughout is suitable to most years and simplifies tracking the evolution of practice usage over time. We therefore concentrated on three-class models, whose parameters are

restricted so that the probability of adoption of a practice will not decrease when moving from cluster 1 to 3. In other words, the models are specified so that the first cluster makes the minimum use of practices and the third the maximum use. All estimated models were identifiable, i.e. for each year the solution was unique, and thus there is support for hypothesis 2. For simplicity, rather than providing the parameter estimates for each model, our results are summarised in Figures 2a to 2d, which show respectively for each year: the average number of practices used in each cluster; the cluster sizes (i.e., number of firms in each cluster); the number of companies per cluster that use each practice (i.e., the diffusion of each practice per cluster); and the probability of usage of each practice per cluster.

Figures 2a-2d

As shown in Figure 2a, practice use increases significantly in every cluster during the period studied, which is indeed consistent with previous observations regarding Britain (e.g., Wood et al., 2004). Firms in Cluster 3 appear to be the innovators, who are then followed by the others. Firms in this cluster use more practices than other firms at every point in time. At the start of the study period, Cluster 3 firms had already adopted an average of about four different practices, which increased to above six at the end of the period, suggesting that most firms in this cluster use all practices in the final year. As Figure 2b indicates, Cluster 3 is initially quite small, but increases in such a way that at the end of the study period it comprises more than 50% of the firms. The observed frequencies of adopting each practice, as shown in Figure 2c, indicate that the typical growth curve that we associate with diffusion processes is only completely seen for Cluster 3.

Firms in Cluster 1 are characterized by a consistently low use of practices, which only increases by around 2000. This cluster comprises about 90% of the firms at the start of the study period, but membership declines steadily over the period. By contrast, Cluster 2, which contains firms with an intermediate usage of practices, increases in size up to 2000, and then shows a decrease, such that by 2001 the data could be reasonably represented by a high and a low usage

group. Indeed, this pattern becomes consistent with previous research, where samples where split in two subsets: basic-advanced users, early-late implementers. Nevertheless, in the present study, this pattern stems from the correlation and evolution of practice use in the sample and not from an arbitrary cutting-point or quality criterion.

The observed frequencies of using a practice and the probabilities of using a practice vary significantly from cluster to cluster. JIT is used less (see Figures 2c) and is basically not used in Cluster 1, but in the more recent years is likely to be used by those in clusters 1 and 2 (Figure 2d – probability of usage is approximately 0.70). Clusters 1 and 2 are closer with regards to the probabilities of using OM practices whereas Clusters 2 and 3 are closer with respect to their likelihood of making use of empowerment in the early and late years (see Figure 2d). The similarities in the evolution of the likelihood of adopting each practice in the clusters (Figure 2d) suggest that, according to the models, supply-chain partnering discriminates at the bottom end, whereas empowerment and teamwork discriminate at the top end. Furthermore, the strongest similarity in the evolution of practice-use (observed frequencies – Figure 2c) as well as in the likelihood of using practices (Figure 2d) is in Cluster 3, which clearly makes the most use of all practices. All figures indicate that firms in Cluster 3 adopt an integrated management approach. Such firms are more likely to mirror those that have been described in the literature as early implementers or as examples of more advanced manufacturing systems.

Testing the link with performance (1982-2003)

We recall that the association between performance and yearly cluster membership is examined by a linear mixed model with time defined as the first level, and company as the second level. A baseline growth model (i.e. with time and the controls as fixed effects), suggested a first-order autoregressive error covariance structure for the effect of time and its fit statistics were the following: -2logLL = 1775, BIC=1814, which show a significant improvement from a null model that estimates the intercept (-2logLL = 5195, BIC = 5210). To this baseline model we added the cluster membership predictors as fixed effects, so that we have the model that we defined in

equation (3). Results are summarised in Table 1. This model is not an improvement in quality of fit (-2logLL = 1779, BIC= 1818), when compared to our baseline growth model, but indicates that belonging to the higher cluster (Cluster 3) is positively associated with performance (t=2.35, p = .019) while belonging to the low-usage cluster is not (t= -.44, p = .66). That is, a high-usage firm outperforms medium-usage firms, though there is no difference between low and medium usage companies nor is the cluster membership a strong predictor of performance.

We note that the lack of difference in performance within the two lower cluster tallies with our initial finding that in more recent years a two-class model would best fit the data. In addition, given our observations on the extent of practice usage in each cluster, we might have concluded that Cluster 3 was the only one making an integrated use of practices. All in all, we have support for hypothesis 3, i.e.: firms that have an integrated HRM-OM approach are high-performers.

Table 1

4.2 The Evolution of Practices

We first estimated latent class growth models for each individual practice. The dependent variable was the practice indicator (0 or 1) and the predictor was the epoch coded 0 to 4, as defined in the analysis procedure. Practice indicators were specified as ordinal variables, and thus a binary logistic regression model was estimated. For each practice, we fitted models with up to five latent classes and chose the model with the lowest Bayesian Information Criterion (BIC). For TQM, empowerment, and ICT the best model was the 3-class model, and for JIT, learning culture, supply chain partnership and teamwork it was the 4-class model. However, for learning culture and supply chain partnership, the fourth class contained less than 1% of cases, so we adopted the 3-class solutions for these practices. The growth models are summarized in Table A1 (Appendix), where we observe the estimated regression coefficients, the quality of fit of the model and the size for each class and practice. These indicate that there are three significant stages in the evolution of the seven practices.

The next step was to cluster the firms based on the seven practice growth models. The indicators for clustering were the seven growth class membership variables, and we estimated models with up to five latent classes. Chi-square statistics dropped dramatically for larger numbers of clusters, and became non-significant (p= 1.00) for more than three clusters, indicating that 3 clusters are sufficient to describe the data, which is consistent with the previous stage of the analysis (Table A1). The classification error rate for this model is 7%, which is quite good. These results that are summarized in Table 2 indicate that firms can be classified according to the evolution (diffusion) of a set of practices and support hypothesis 4.

Table 2

We used these final clusters to classify each company based on the evolution of the seven practices. Consequently, we have a clearer picture of the year-on-year implementation of each practice for each class, as shown in next figure.

Figure 3

Firms in Cluster 3 are early adopters, who tend to make an integrated use of practices early on. However, in this cluster the rate of further introduction of a practice is relatively slow; by midway through the study period, adoption of the three HRM practices and JIT reaches a plateau, although adoption of TQM, ICT and supply chain partnering continues to rise. Firms in Cluster 2 start from a lower base, but show rapid change over a relatively short period. In fact, by the end of the study period, firms in this cluster have a higher probability of using every practice than those in the other two clusters. Cluster 1 firms also start from a low base, but are reluctant to get started, and adoption of practices only begins to rise in the middle of the study period. From this point however, adoption is fairly rapid, so that by the end of the period studied, the adoption rate in this cluster is comparable to that in Cluster 3.

Assessing the link with performance

Recalling that accounting data was not available in every year for every firm, we tested for a possible effect of practice adoption trajectories on performance, by examining value-add in the last available accounting year as a function of trajectory class. The controls were company size and fixed assets in the final accounting year, value-add in the initial (first available) accounting year, and the number of years (accounting period) between the initial and final accounting years. We estimated a General Linear Model with final log value-add as the dependent variable. Initial log value-add, log final company size, log final fixed assets and accounting period were entered as covariates, and the trajectory class was the categorical predictor.

Table 3

The results are shown in Table 3, where we observe a significant effect of trajectory class on final performance, which is indicated by its partial Eta-squared value (last column). After accounting for the control variables, trajectory class membership explains 4.2% of the remaining variation in final firm performance. Pair-wise comparison tests showed that early adopters of the integrated approach significantly outperformed both late and intermediate adopters ($p < .05$) in the final accounting year, but there was no significant difference between the late and intermediate adopters. In spite of the similarity in performance between late and intermediate adopters, we have some indication that early adoption is beneficial to the firm. We note that these results were confirmed by a similar model where the initial performance was measured as the average of the first two available years and similarly the final performance was the average of the last two years. Furthermore, hierarchical regressions, where a baseline model had the covariates as controls and the second model had additional dummy variables that indicated early and late adopters also showed that early adopters were positively associated with final performance. When we recall that by the end of the period studied intermediate adopters make a similar or even greater usage of the practices than early-adopters, this result suggests first-movers advantage.

5. Discussion and Conclusion

This paper provides empirical evidence on the association between modern management practices and firm performance in British manufacturing over twenty years. In contrast to previous work, which tended to investigate potential effects of either individual practices or specific combinations, it focuses on the overall correlation in practice use. In doing so, practices are treated as a package and the focus is on integration that would reflect a managerial approach that combines OM and HRM and thus would have the ability to achieve multiple goals and result in superior firm performance.

Although, some authors would argue that in manufacturing operations management and processes are prioritised, we found no evidence of HRM being neglected in favour of OM. In fact, OM and HRM practices are strongly associated in our data. The use of the seven practices evolved in a similar fashion during the twenty-four years studied. For each year, three latent class clusters of firms (low, medium and high usage) were identified. The adoption of practices was indicative of a single dimension, which is not a continuum but defines stages in the development of a management approach that is solely responsible for the correlation in practice use. In all, the assumption that practices are only manifest of a latent philosophy and that they would be independent in the absence of this philosophy, which might initially have seemed quite strong was supported by the data. Indeed, this result consistent with previous findings from a cross-sectional study of British workplaces in 1998 (de Menezes and Wood, 2006), where respectively three homogeneous groups that progressively adopted HRM and TQM practices were identified, without order restrictions being placed. Yet, JIT was found to be a separate dimension and supply chain partnership was not included in the set of practices. Consequently, one could not establish that a lean production philosophy was in place. By contrast, the current results, though based on smaller set of practices but which includes core elements of lean production, show a consistent pattern over 24 years and add support for the research framework that views lean production as an integrated concept or managerial philosophy. Indeed this is important, because pursuing the goals of this philosophy is

then what matters; as a result, different combinations of practices are only manifestations of a managerial approach. The choice of practices is no more driven by expectations on the performance of specific combinations, but by having a system in place. The focus switches from potential efficient bundles of practices to the unobserved philosophy or management approach that may be manifested via different bundles.

Results showed that firms in the most advanced cluster did not only adopt more practices, but also were likely to be the one of the first adopters. Furthermore, within the period studied, some firms moved between clusters so that in the final years a two cluster might as well have been identified. In fact, this could be a consequence of our focus on a set of the most widely used practices within a single industrial sector. Similarities between firms could have facilitated the spread of practices. Yet, not all firms moved and, although the lower-usage cluster became smaller with time, some firms have lagged behind the majority (or perhaps the sector). In which case, they are either more resistant to innovations or lack the investment capacity. Given the limitations of our data set, we are unable to identify other factors that could explain this perceived stagnation and we therefore look forward to further work on different industries and a wider set of practices to clarify these findings.

Our two-level hierarchical regression model showed that firms in the more integrated and high-usage cluster were likely to outperform the others, but also that cluster-membership is a weaker predictor of performance. Consequently, we have support for the expectation of a positive association between lean production and performance in British manufacturing, albeit we acknowledge that other firm characteristics are important. The ability to establish a link with performance highlights our view that management practices should be considered as a package and therefore one should focus on integration rather than specific synergies. As a matter of fact, Birdi et al. (2008) found few synergies in a similar dataset, according to their results, only teamwork interacts with most practices and empowerment is the key practice. They found no evidence of interaction between OM practices and concluded that the data did not support some of the

expectations that are based on the lean production concept. Our results suggest that empowerment and teamwork may discriminate between medium and high usage firms, whereas supply chain partnership may discriminate at the bottom end. The latter may be due to the fact that partnerships require contracts (commitment), which can deter the spread of the practice by acting as a barrier, especially if a firm has limited resources or a short-term strategy.

Based on the diffusion of each practice in the sample, we re-classified firms according to their stages in adopting practices. The data unveiled three groups: early adopters, intermediate adopters and late adopters. In addition, we observed that, at the end of the period, intermediate adopters had not only caught up with early adopters but were even making more use of practices. Nevertheless, early-adopters outperformed the others. This final result supports the initial claims that led to the spread of TQM as a management philosophy, which is that a cohesive management system can become a source of competitive advantage. Although it appears that some of the early adopters in our sample were initially high performers, since we controlled for initial performance and considered alternative models, we do have some indication of potential first-mover's advantage and long-lasting effects. It could also be that some of the benefits are long term and thus we were unable to observe the performance gains of the intermediate adopters. This can be further investigated within the more encompassing concept of lean production, and preferably beyond manufacturing.

In this study, we lack information as to the extent of use of practices and rely on single-item measures, but generally our results are quite positive as well as give us insights into the potential evolution of lean production in British manufacturing. Latent class models enabled the identification of clusters without the need for either arbitrary criteria (e.g. award winner, "efficient" implementation) or pre-specified bundles. These models can be extended to ordinal or continuous manifest variables, as well as allow for different levels of measurements and restrictions to be added. As such, they are powerful clustering tools that can be used in future studies of management practices.

To sum up, this is the first longitudinal study that addresses the co-existence of management practices as an integrated management approach that is a kin to lean production. It uses ordered restricted latent class models to identify homogeneous clusters of firms and establishes a positive link with performance. In addition, an analysis of the diffusion of each practice resulted in an alternative classification that describes three stages of adoption. Consequently, there is support for analysing practices as a package plus evidence that earlier integration is indeed associated with performance. In all, the benefits of lean production appear to be sustainable and an integrated managerial system is potentially a source of competitive advantage, thus highlighting the importance of continuous improvement and learning that are vital to the concept.

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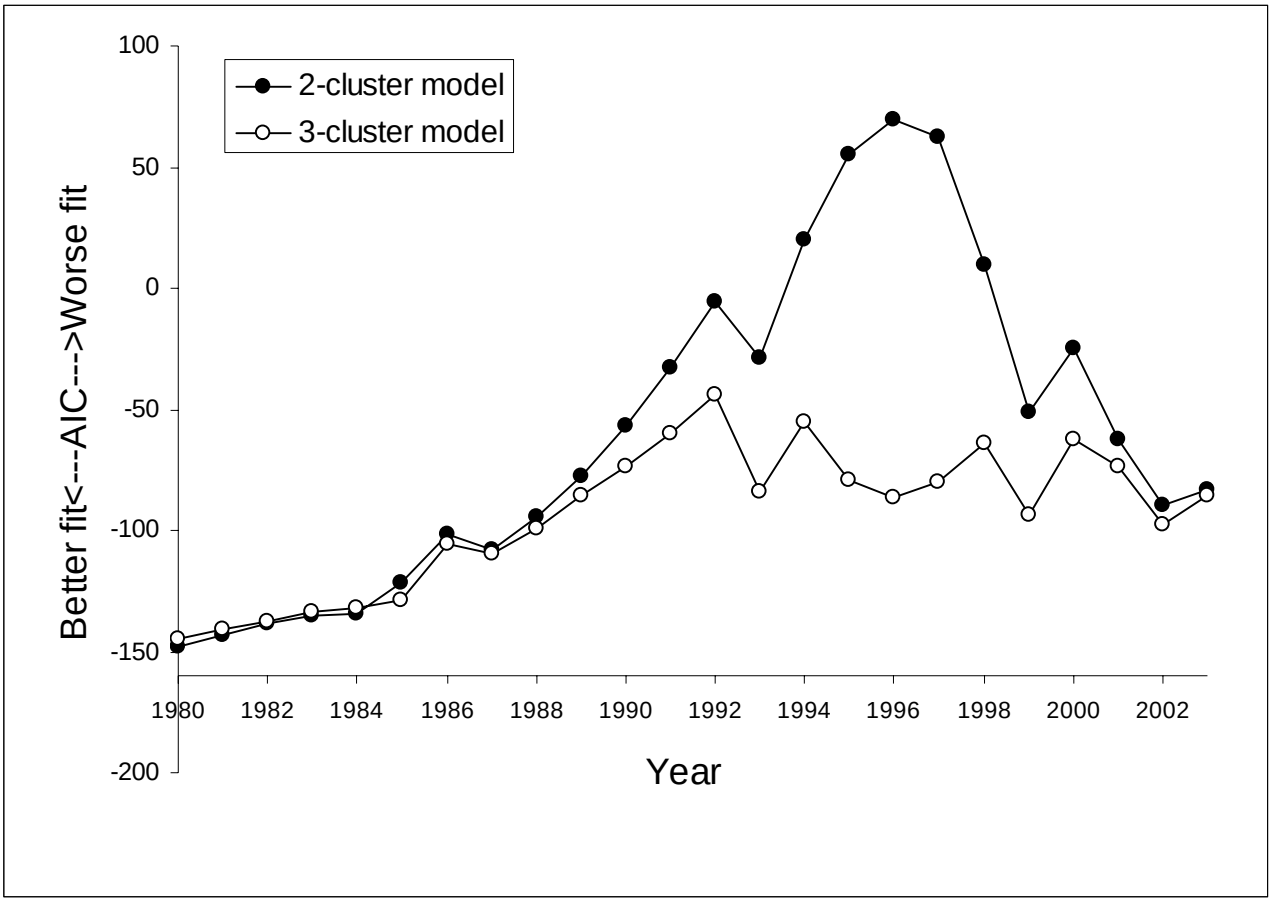


Figure 1: Akaike Criterion – Latent Class Models

Figure 2a. Evolution of practice usage

Figure 2b: Evolution of cluster membership

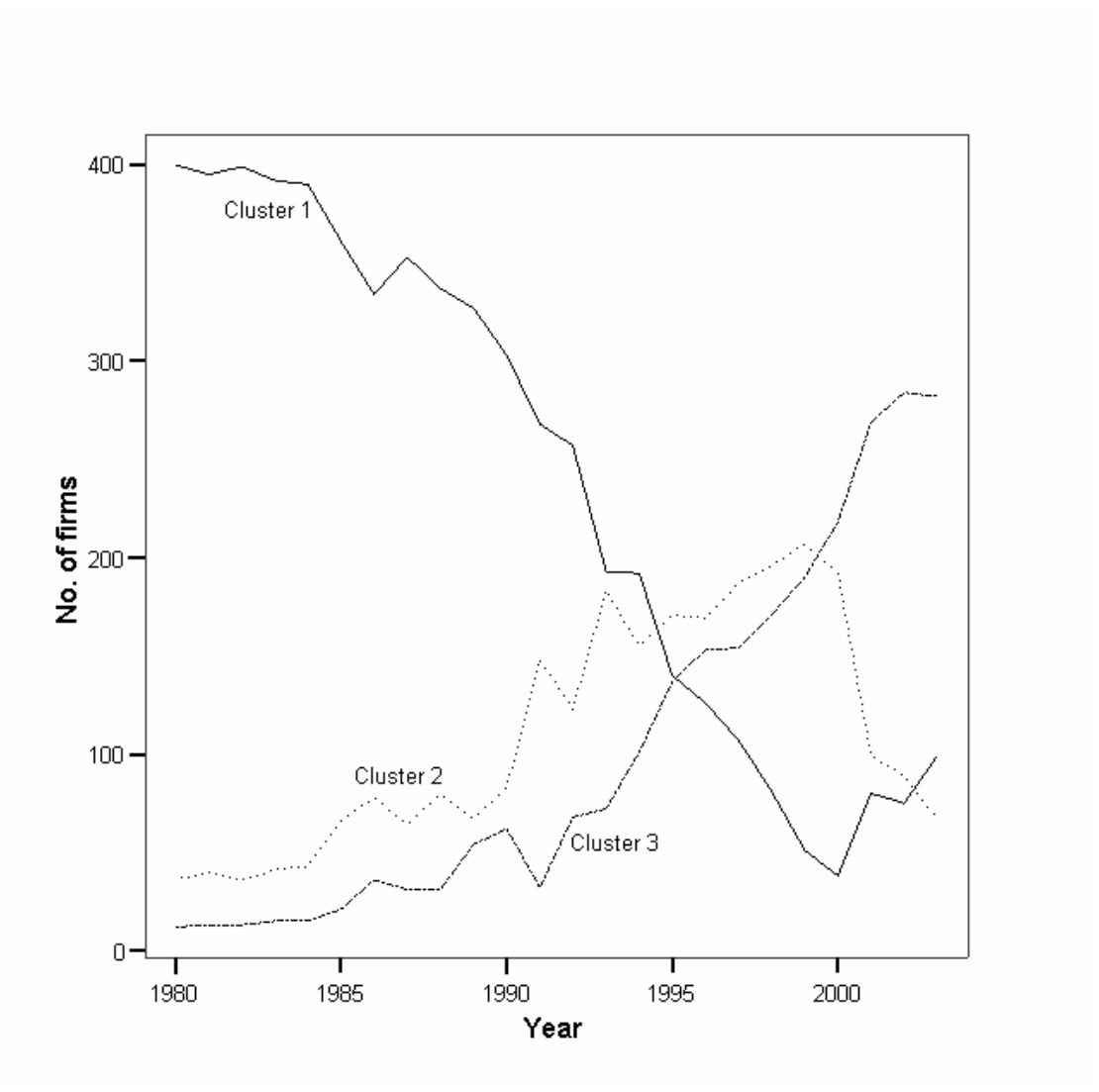


Fig. 2c: Frequency of practice usage by cluster and year

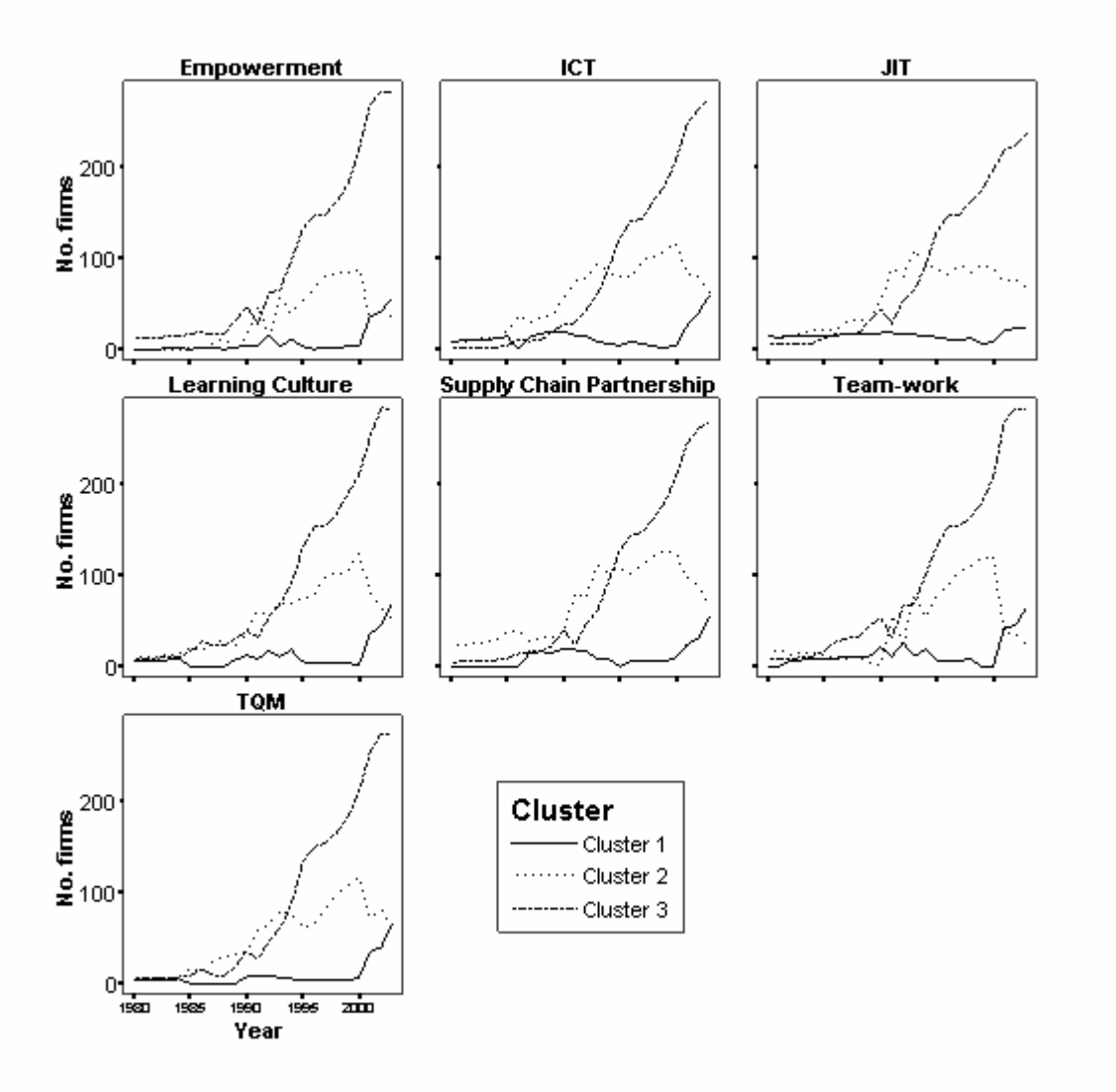


Figure 2d: Probability of practice use given cluster membership.

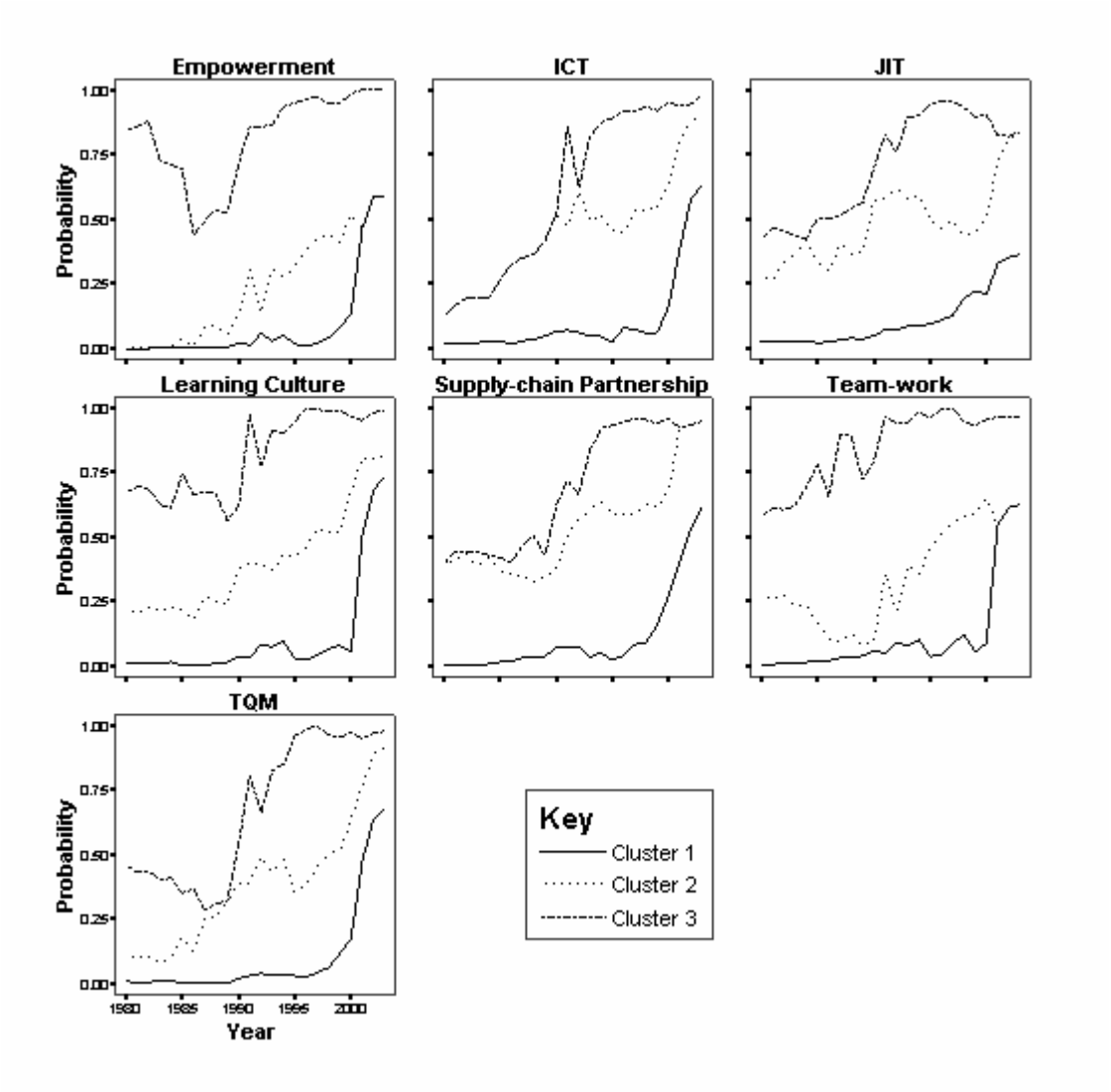


Table 1: Cluster Membership and Performance – Estimates of Fixed Effects

	Baseline Model			With Cluster Membership Added		
	Estimate	Std Error	t	Estimate	Std Error	t
Intercept	9.35	0.181	51.62**	9.42	0.185	50.98**
Assets	0.10	0.016	6.47**	0.10	0.016	6.34**
Size	0.85	0.023	36.49**	0.84	0.023	36.51**
Time	0.01	0.003	3.22**	0.01	0.003	2.00*
Cluster 1				-0.01	0.027	-0.44
Cluster 3				0.06	0.025	2.35*

* p ≤.05
** p ≤.01
Dependent variable: log value-added

Table 2: Final Three-Class Solution based on the Evolution of Practice-Use

	Cluster	Late adopter	Intermediate adopter	Early adopter
	Cluster Size	46.8%	40.6%	12.6%
Management practice	Growth class	Probablity[a]		
TQM	1	.37	.82	.31
	2	.62	.04	.33
	3	.02	.15	.36
JIT	1	.61	.10	.37
	2	.12	.63	.25
	3	.23	.20	.02
	4	.04	.07	.36
Learning Culture	1	.35	.88	.12
	2	.64	.02	.23
	3	.01	.10	.65
Supply-chain partnering	1	.42	.79	.26
	2	.53	.06	.22
	3	.05	.15	.52
Teamwork	1	.70	.38	.01
	2	.11	.55	.26
	3	.17	.03	.36
	4	.02	.04	.37
Empowerment	1	.29	.87	.25
	2	.69	.06	.40
	3	.01	.07	.36
Integrated computer technology	1	.36	.64	.39
	2	.61	.08	.25
	3	.03	.28	.36

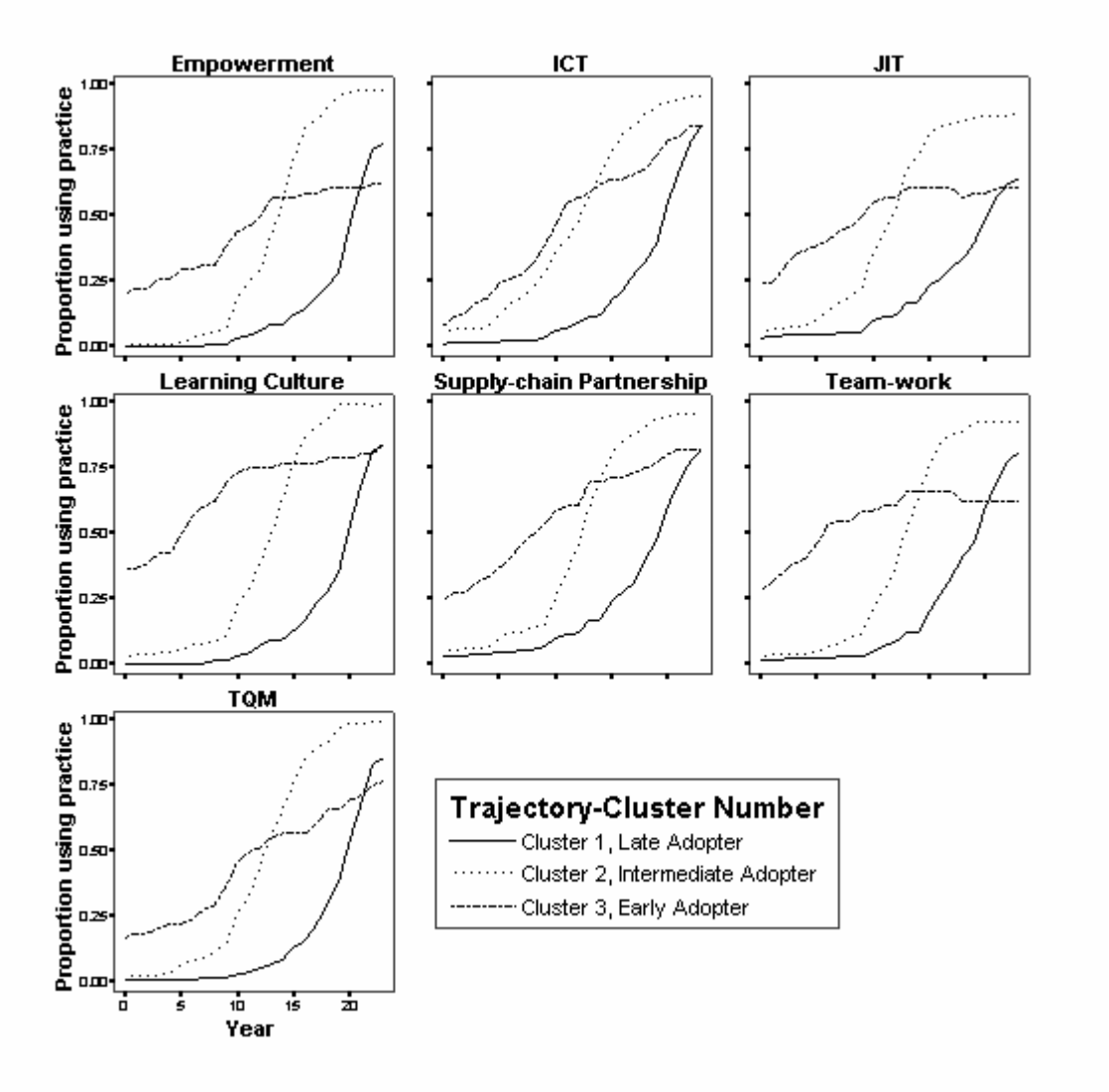
[a] Probability of belonging to growth class conditional upon Cluster membership.

Table 3: Performance and evolution of practice

Source	Mean Square	F	Partial Eta-square (%)
Corrected Model	41.3	181.8***	87.9
Intercept	70.7	311.3***	67.5
Initial value-add (log)	0.1	0.6	0.4
Final fixed assets (log)	2.2	9.8**	6.1
Final size (log)	45.9	202.0***	57.4
Accounting period	0.0	0.0	0.0
Trajectory class	0.8	3.3*	4.2
Error	0.2		

Note: Dependent variable is Value-add in the final accounting year (log). R-Sq = .88.
*** p < .001 ** p <= .01 p <=.05

Figure 3: Practice evolution trajectories: Proportion of firms using each practice.



Appendix

Table A1: Latent Class Growth Models

Practice	Class	Estimated Regression Coefficients		R-square	Class Size
		Intercept	Epoch		
TQM					
	1	0.60	6.98	.80	51.1%
	2	0.30	3.02	.57	37.6%
	3	-0.90	4.46	.58	11.3%
JIT					
	1	0.36	5.08	.19	32.4%
	2	0.30	6.48	.82	30.4%
	3	0.21	2.79	.72	27.8%
	4	-0.87	-2.52	.06	9.4%
Learning Culture					
	1	0.52	6.96	.80	48.8%
	2	0.28	2.57	.54	38.2%
	3	-0.80	4.24	.41	13.0%
Supply-chain partnering					
	1	0.66	3.95	.78	55.8%
	2	0.03	5.56	.53	29.6%
	3	-0.68	4.39	.39	14.6%
Teamwork					
	1	0.94	3.16	.71	50.3%
	2	0.38	6.43	.86	28.6%
	3	-0.35	1.42	.01	13.8%
	4	-0.97	-2.84	.10	7.4%
Empowerment					
	1	0.65	6.85	.80	50.4%
	2	0.43	3.68	.51	40.7%
	3	-1.08	1.63	.40	9.0%
Integrated computer technology					
	1	0.46	3.82	.77	48.5%
	2	0.13	5.89	.64	34.6%
	3	-0.59	4.88	.59	17.0%