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**The integration of human resource and operation management practices and
its link with performance: A longitudinal latent class study**

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Abstract

This paper reviews the literature on the association between lean production and performance. From this, propositions on the integration and evolution of operation and human resource management practices associated with the lean production concept are developed. Using 24 years of data on the use of seven core OM and HRM practices in British manufacturing firms, the potential link between integration in the use of practices and productivity is tested. In each year, three latent clusters are identified via ordered restricted latent class models; the cluster that consistently makes a more integrated use of practices outperforms the others. Furthermore, the longitudinal nature of the data permits modeling the growth curves of each practice in the sample, recognizing any similarity in growth and investigating whether or not an early integration in adoption of practices is associated with higher final productivity. The results show that pioneers are more productive, thus suggesting that the head start in integrating core OM and HRM practices associated with the lean production concept has paid off.

Keywords: operation and human resource management practices; lean production; performance; latent classes, latent growth and multi-level models.

1. Introduction

Markets are increasingly more competitive and global, so quality standards and product or service efficiency is crucial to the survival of any organization. In this context, the lean production concept has been increasingly advocated beyond manufacturing (e.g. in services: Abdi, Shavarini and Hoseini, 2006; Abernathy, Dunlop, Hammond, and Weil, 2000; Swank, 2003; in the public sector and healthcare: Kollberg, Dahlgard and Brehmer, 2007). The spread and interest that it has attracted are possibly due to claims of cost and waste reduction, superior performance and competitive advantage that have been consistently made by academics and practitioners alike (e.g. Chandler and McEvoy, 2000; Dennis, 2002; Hart and Schlesinger, 1991; MacDuffie, 1995; Powell, 1995; Womack and Jones, 1994; Womack, Jones and Roos, 1990; Wood, Stride, Wall and Clegg, 2004; Youndt, Snell, Dean and Lepak, 1996). Despite controversies about the precise meaning of lean production (Li, Rao, Ragu-Nathan and Ragu-Nathan, 2005; Shah and Ward, 2007), it has commonly been taken to involve techniques concerned with production, work organization, quality management, logistics, supply chain, customer satisfaction, efficient delivery and continuous improvement methods. In other words, the adoption of lean production implies integration in the use of operation (OM) and human resource management (HRM) practices.

The quality management literature, which can be traced back to 1949 when the Union of Japanese Scientists and Engineers formed a committee to improve Japanese productivity (Powell, 1995), also offers competing definitions for total quality management (TQM). Some authors argue that it is a managerial philosophy (e.g. Martinez-Lorente, Dewhurst and Dale, 1998), whose principles imply an integration of operations and people management (Wickens, 1987). Yet Deming (2000) focused on an organizational system that promotes cooperation and learning for facilitating process management, resulting in the constant improvement of processes, products and services, as well as employee fulfillment and customer satisfaction. This system, then, becomes critical to the survival of organizations (Anderson, Rungtusanatham and

Schroeder, 1994). Juran (1993) emphasized not only team and project work, participation and recognition, but also highlighted the need to achieve the best return on investment. According to him, the primary responsibility of management is to minimize the total cost of quality and to decide when quality management efforts should be stopped. Deming also argued that the improvement of the work process reduces cost because of less re-work, fewer mistakes or delays and less waste in manpower and materials, but (in contrast to Juran) prescribed constant improvements.

In this context, important questions for managers and scholars are: How do different managerial practices impact on performance? Which practices have greater impact on performance outcomes? Does the integration of operations management and human resource management practices pay off? Are expectations of long-lasting gains fulfilled? For several decades the link with performance has mainly been investigated by addressing the first two questions. However, not only do results and measures vary within studies but the focus has generally either been on individual practices or sets of practices that are presumed to result in superior performance. For example, a common view is that HRM practices – for instance those that empower or involve the employee – support specific OM practices; jointly they have a higher, possibly nonlinear, effect on performance (Kufidu and Vouzas, 1998; Lawler, Mohrman and Ledford, 1995; MacDuffie, 1995). Longitudinal studies remain rare and tend to rely either on subjective assessments of practice implementation (Easton and Jarrel, 1998; Fullerton, McWatters and Fawson, 2003) or on relatively short periods (e.g. Callen, Fader and Krinsky, 2000; Capelli and Neumark, 2001).

In this paper, we concentrate on the integration of HRM and OM practices and its potential impact on performance, by reviewing the empirical literature and developing a set of propositions, which we then test. In our analysis, we assume that there is a philosophy or culture underlying the integration of OM and HRM practices, whose principles are not only concerned with eliminating waste and adding value for customers but also entail the pursuit of continuous

improvements. The latter cannot be achieved without worker participation, such as quality at source inspections that imply responsibility for checking one's own work. Learning and cooperation thus facilitates process management, and integration should continue to pay over time; those organizations that adopt this managerial philosophy should outperform those that do not.

We use secondary data of 448 British firms (Birdi, Clegg, Patterson, Robinson, Stride, Wall and Wood, 2008) on seven management practices that are the most extensively employed in British manufacturing (Wood et al., 2004), and company records for the period 1980–2003. Of the seven management practices, 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 the lean manufacturing system and the last adds the customer–supplier relationships that are necessary for the delivery of desired standards at a minimum cost. HRM practices included are learning culture (or extensive training), empowerment and teamwork. The first two have consistently been associated with quality management, as shown by the criteria of the 1992 Baldrige Award (George, 1992) and can be easily traced back to two of Deming's 14 points (Walton, 1986). Empowerment has been described as critical to successful JIT initiation and implementation (Koufteros and Vonderembse, 1998), whereas teamwork is core both to high involvement (Bailey, 1993; de Menezes and Wood, 2006) and quality managements (Wickens, 1987). Together, we would expect that these HRM practices will allow employees to enhance their knowledge of the company, work more flexibly, and take more responsibility in quality management and decision-making.

By focusing on the philosophy that underlies the co-existence (correlation in the use) of different types of practices, we also address the measurement problem that has been identified in the academic literature (e.g. Shah and Ward, 2007). This is done not in terms of what should be included in the measure, but in terms of how it should be constructed. If the lean production

concept implies a managerial philosophy, culture or way of thinking, as advocated in the literature (Womack and Jones, 1994), the co-existence of OM and HRM practices that are traditionally associated with this concept should reflect this philosophy. Moreover, if this philosophy is geared towards improving performance, the direct link between the philosophy and performance should be investigated rather than the association between its elements and performance. If practices co-exist, the longitudinal nature of our data also permits an assessment of the overall evolution of practices and the association with performance. Our longitudinal study thus investigates whether: (1) the integrated use of core OM and HRM lean practices is associated with higher performance; (2) there are performance gains from being an early adopter of such an integrated approach.

In the following sections, we review the empirical evidence on the link with performance as well as the literature on the evolution of management practices, which set the background to the propositions that are tested. We then describe the data, the methodology that we use and report our results. Finally, we assess our contribution and conclude.

2. Background

Empirical studies of the link between a lean production philosophy and performance have concentrated on assessing whether one or more of its elements are key, or whether combinations of these lead to higher performance. In general, cross-sections were analyzed; definitions of constructs as well as sample sizes vary considerably. Consequently, it is not only difficult to compare studies, but, as observed by Shah and Ward (2003: 130), analyses of the performance effects that focus on multiple components of lean production remain rare.

In the HRM literature, diverse sets of practices have been assumed to be part of a high performance work system (Becker and Gehart, 1996; Huselid, 1995) and as such are linked with performance. Fundamental practices like empowerment or work enrichment that we would associate with the high involvement concept (Bailey, 1993) are often omitted in empirical

analyses. Results on the link with performance also reflect the diversity in measurement constructs and dependent variables (Wall and Wood, 2005). The empirical evidence ranges from positive association with all practices (Arthur, 1994), to lack of association and even a negative correlation (Capelli and Neumark's 2001 panel study showed no association, but one practice was negatively related to both productivity and its change).

Overall, longitudinal studies are rare and the potential impact of integrating practices has been generally neglected, though it is often argued that practices should be adopted in an integrated fashion. We now review the empirical evidence from studies on quality management and lean production, which justify our assessment of the current state of the literature and the need for studies like ours.

2.1 The empirical evidence on the link between lean practices and performance

Initial reviews of the evidence reported a lack of association between practices and performance. Powell (1995) offered several anecdotal examples where the costs of implementing a TQM strategy outweighed its benefits. Reed, Lemak and Montgomery (1996) concluded that any observed benefits were simply contingent on matching environmental conditions to firm orientation. Samson and Terziovski (1999) argued that the lack of evidence was due to small samples and measures that did not reflect the various dimensions of quality management. They examined the relationship between TQM and quality, operational and business performance in Australian and New Zealand manufacturing (n=1200), using multi-item measures that were thoroughly constructed and validated. A positive link with performance was then observed, but not all categories of TQM were strong predictors of performance. It appeared that gains from quality management might be due to the interaction of practices, thus leading to subsequent research where synergistic effects were found between distinct elements of lean (JIT, TQM, HRM) on multi-item measures of manufacturing and employee performance (Challis, Samson and Lawson, 2002).

Indeed, the search for promising combinations of practices has been a dominant subject of empirical research (e.g. Bou and Beltran, 2005; Cua, McKone and Schroeder, 2001; Dow, Samson and Ford, 1999; Flynn, Sakakibara and Schroeder; 1995; MacDuffie, 1995; Narasimhan, Swink and Kim, 2004; Shah and Ward, 2003). Flynn et al. (1995) claimed that TQM and JIT mutually support each other: TQM reduces process variance, which can simplify the manufacturing process and closely match production and customer demand, while JIT affects quality management by reducing lot sizes and thus decreasing potential waste and re-work. Besides the combination of TQM and JIT, Flynn et al. argued that other practices (a combination of OM and HRM that they named infrastructure) should interact with either of them. Their sample of US manufacturing plants (n=42) within three industries (machinery, transportation components and electronics) showed strong synergistic effects on quality, but these were especially from combinations that also included HRM practices. The potential gain from the interactions with HRM practices was also observed by MacDuffie (1995) in a seminal study (n=62) that was part of a wider investigation on the human resource side of lean production, using data from the MIT *Future of the Auto Industry* project. According to two performance criteria – productivity (hours taken to build a vehicle adjusted by relevant factors, e.g. size) and quality (defects/vehicle) – MacDuffie’s results showed significant synergies between OM and HRM systems.

Positive interactions between supply-chain and total quality managements have also attracted considerable interest (e.g. Carter and Narasimhan, 1996; Carter, Carter, Monczka, Slaughter and Swan, 2000; Mehra and Inman; 2004). The predominant view is that TQM expands 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. A minimum integration of OM practices is required to achieve this effectiveness, and thus one would expect a significant correlation between the uses of TQM, JIT and supply-chain practices. Flynn and Flynn (2005) tested for synergies between

the perceptions of how extensively TQM and supply-chain management were employed on a sample of manufacturing plants from five industrialized countries (n=164). Their TQM measure included JIT delivery and HRM practices and is thus broader than most studies. Overall, TQM supported supply-chain management, though not all combinations of practices were positively associated with all measures of performance (quality, volume flexibility, manufacturing cycle time, on-time delivery).

With a few exceptions (e.g. Cua et al., 2001; Challis et al., 2002), most studies have concentrated on just two elements of lean, though in some cases HRM practices might have been included within TQM. Shah and Ward's (2003) study is one of the most comprehensive, since it focused on multiple elements in a large sample of US manufacturing plants (n=1,757) from several industries. Plants were classified into four bundles of related processes and procedures: JIT, TQM, HRM and TPM (Total Preventive Maintenance). After controlling for industry, union presence, size and age of plant, the adoption of these bundles was positively associated with operational performance, measured as the five-year change in six items (scrap and re-work costs, manufacturing cycle time, first pass yield, labor productivity, unit manufacturing cost and customer lead time). Shah and Ward then concluded that "a separate and identifiable incremental effect can be attributed to the four major lean practices areas" (2003: 145–146), and that these findings provide "unambiguous evidence that the synergistic effects of all lean practices are associated with better manufacturing performance". Thus, all elements should coexist, though they did not formally test for the four-way interaction (synergy) nor modeled a secondary factor (integration).

To sum up, the literature supports synergies between the different practices and we would expect OM and HRM practices to coexist, at least in the long run. It is reasonable, then, to expect significant correlation between the different elements of lean production, and we propose:

Proposition 1: OM and HRM practices that are associated with the lean production concept are integrated.

Yet in the literature addressing the potential link with performance, the analysis of the correlation structure has been limited to separate elements of lean. Potential synergies between two or three elements tend to be analyzed, thus implying that elements may be perceived as being independent. As an example, we refer to Bou and Beltran (2005: 71), who claimed that “the influence of TQM on organizational results will be greater when its implementation is supported by a high-commitment strategy”, and therefore HRM and TQM should have a synergistic effect on performance. They tested this hypothesis via a structural equation model, where TQM and high commitment management (HRM practices) are two independent latent variables that positively interact on financial performance (Bou and Beltran, 2005: 81, figure 2). 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”, but did not test for this integration by assessing whether their two latent variables were correlated and loaded on a single dimension. Moreover, by assuming that the correlation between TQM and the HRM-centered commitment variable is negligible, they contradicted their observation that the correlation could be significant, as 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” (Bou and Beltran, 2005: 75). In short, despite acknowledging their expectation of integration between OM and HRM, the authors followed the general trend in the literature and limited the investigation to synergistic effects. Proposition 1 remains to be tested.

2.1.1 The potential link between the integration of lean practices and performance

The first stage in examining a link between the integrated use of practices and performance is an assessment of integration. Few authors have actually modeled the correlation in the adoption of different types of practices when developing their construct. Among those that did, not all assumed that underlying the correlation between practices (or elements) was a management philosophy. For example, Callen, Morel and Fader (2003) investigated the risk–profitability trade-off of JIT manufacturing (lean) on a sample of 100 plants. Seventeen practices were considered, of which only two can be broadly classified as HRM (quality circles and flexibility of worker’s skills). Principal component analysis was used to develop an index of JIT manufacturing, which is therefore a formative rather than a reflective construct (latent variable). By choosing this statistical method, as described by Diamantopoulos and Sigauw (2006), the authors assumed that the use of practices causes the construct being measured (JIT manufacturing) and not that the coexistence of practices reflects an underlying managerial approach. According to each plant’s score, the sample was then split: JIT manufacturing (lean), non-JIT and the first group of plants were found to be more profitable, even after adjusting for the operational risks relative to non-JIT manufacturing. Had similar results been found based on a construct derived from factor analysis, we would have evidence of a link between integration and performance.

Fullerton et al. (2003) examined the link between JIT (lean) manufacturing systems and financial performance (profitability: return on assets, return on sales and cash flow margins) in 253 US manufacturing firms. They argued that the conflicting empirical evidence (see Kinney and Wempe, 2002, who extended the work of Balakrishnan, Linsmeier and Venkatachalam, 1996, but in contrast to them found a negative link) suggested that the degree of implementation affects the link and thus any measure should consider the extent of implementation. Hence, based on the extent to which 10 practices were implemented, they found three factors: JIT manufacturing, which underlies the adoption of OM and HRM practices, JIT quality and JIT unique, both of which have underlying pairs of OM practices. Cross-sectional and longitudinal

links with financial performance were examined, with the respondents' self-assessments as JIT adopters being the basis of the longitudinal investigation. Only JIT manufacturing, which is the factor that integrates HRM and OM, paid off and its level of implementation and maintenance led to sustainable rewards.

Kaynak (2003) developed a structural equation model of potential effects of HRM and TQM on perceived financial, market and operating performances relative to the competition, which was tested on a sample of US manufacturing and service firms (n=42). In contrast to most studies, the model (Kaynak, 2003: 414, Figure 1) shows some integration between OM and HRM – for instance, management leadership is a latent variable that loads on HRM and quality management practices. Results supported all paths in the model, and the author concluded that a range of TQM practices had positive effects on firm performance and thus “practitioners as well as researchers cannot simply pick and choose a few techniques to implement” (Kaynak, 2003: 427).

Nahm, Vonderembse and Koufteros (2003, 2004) examined the relationships between organizational structure (number of layers in the hierarchy, level of horizontal integration, locus of decision-making, nature of formalization and level of communication), culture, composite measures of manufacturing practices (re-engineering setups, cellular manufacturing, quality initiatives, preventive maintenance and pull production) and performance (sales, growth, return on investment, market share gain and overall competition). In their structural equation models, OM practices load on to a latent variable that is shown to mediate the link between performance and both organizational structure (Nahm et al., 2003) and organizational culture (Nahm et al., 2004). Overall, they demonstrated that managerial beliefs, locus of decision-making and level of communication are associated with what they call time-based manufacturing practices (OM latent variable), directly linked to performance. Although these elements may be expressed by HRM practices, in their framework the authors have not explicitly examined the association between OM and HRM practices.

The integration of TQM and HRM practices and its association with performance have been explicitly investigated by de Menezes and Wood (2006) in a representative sample of British workplaces (n=2191). According to their results, TQM and HRM practices loaded on a single discrete factor, but JIT was a separate element. Their integrated HRM–TQM measure was associated with subjective measures of workplace performance (labor productivity and its change).

To sum up, the above studies suggest that the integration between OM and HRM practices as prescribed by the lean production concept may be associated with performance and we propose:

Proposition 2: The integration of OM and HRM practices associated with the lean production concept is linked to performance.

Most studies did not set out to investigate this link and only one study was longitudinal. We need evidence, especially from longitudinal studies because they enable the investigation of the associations over time, of 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.

We now consider two longitudinal studies, namely Patterson, West and Wall (2004) and Birdi et al. (2008), because they were based on the Institute of Work Psychology (University of Sheffield) Modern Management Practices Survey Series, from which we draw our data. Patterson et al. (2004) 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 labor 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.

Birdi et al. (2008) extended the analysis to 22 years and seven practices: empowerment, extensive training (learning culture) 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. They examined the association with productivity, but the focus remained on separate practices; only empowerment and extensive training were positively associated with productivity, representing gains of at least 6%. Their conclusions on the link between individual practices corroborated the earlier study (Patterson et al, 2004): OM practices on their own and the combination of the four were not linked to performance. Yet there were synergies: teamwork interacted with most practices; four of the six two-way interactions between OM practices were positively linked to productivity, and supply-chain partnering appeared to enhance the effect of all other OM practices. Moreover, they observed a high proportion of positive two-way interactions between HRM and OM practices, which they concluded to be a support for the lean production concept “that the effectiveness of operational practices depends on human resource ones” (Birdi et al., 2008: 493).

We will revisit this second dataset and further explore its longitudinal nature. In contrast to previous work, we will focus on the integration and the association in the evolution of practices, based on which we may identify different stages of adoption and any link with performance, as we discuss below.

2.2 The evolution of lean management practices and performance

To understand the evolution of OM and HRM practices, we refer to Powell (1995: 20–21) and his use of the diffusion of innovation literature (Rogers, 1983). Diffusion of innovation refers to the spread of concepts, technical information and actual practices within a social system. The spread denotes a flow from a source to an adopter, typically by communication or influence (for example, the adoption of lean practices by Japanese subsidiaries in the UK). Diffusion trajectories as a function of time (growth curves) 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 is observed and modeled in many areas, as described in Wejnert's (2002) review of diffusion processes. In management, the spreads of specific practices have rarely been investigated. Bryson, Gomez, Kretschmer and Willman (2007) and Freitas (2008) use British data from the Workplace Employment Relations Surveys and focus on workplace characteristics that predict the diffusion of HRM practices. They argue that practices are governed by considerations of costs and benefits that are similar to those involved in any innovation and thus can be examined by diffusion models. The first study measured the diffusion or intensity of HRM through an additive score, while the second focused on specific practices and their implementation. Neither modeled the growth curve nor focused on performance, for both aimed to identify factors that may predict diffusion. They found that industrial sector, size and age of the establishment, set-up date and number of organizational affiliations are associated with diffusion. Such results are consistent with the general view that innovations propagate more rapidly among those that share similar visions, values and approaches. Consequently, firms can be classified based on their stages of adopting a managerial philosophy and we propose:

Proposition 3: There is a pattern in the evolution of lean practices, so firms can be classified according to their adoption stages.

Few studies have examined the link between the stages of adopting a managerial philosophy and performance. Among this literature, Easton and Jarrell (1998) developed an event history study on the impact of TQM between 1981 and 1991. Implementation was judged according to the Baldrige Award criteria, in which case an advanced implementation would combine OM and HRM practices (George, 1992). Each firm's performance (accounting and stock returns) was compared with a control benchmark that captured what performance would have been without TQM. 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, which led the authors to support the view of a longer-term impact. Yet 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. Moreover, Fullerton et al. (2003: 400) observed that greater degrees of implementation of JIT quality practices decreased profitability, but JIT manufacturing that integrated OM and HRM showed sustainable profits. All in all, we lack coherent evidence on any link between the evolution of management practices and firm performance, possibly because of sampling variations, different constructs and measures, but also due to distinct perspectives on long-term effects.

We may argue that expectations of long-term effects could discourage diffusion, because only firms that have higher investment capacity would be willing to adopt an innovation and wait for medium- or long-range returns. In which case, a higher performance would be associated with early adoption. Furthermore, the diffusion process and its link with performance can be highly influenced by learning effects, which may create asymmetries among firms and affect the spread of adoption. In fact, when practices are viewed in bundles, learning can be subject to considerable variance: some features are easily transferable, others may suffer great resistance; therefore, investment can be perceived as too risky. Innovators would then be those that have low transaction costs, are willing to take the risk, or have the capacity to invest in continuous learning. Early adopters would then benefit from the sustainable learning and continuous improvement that are commonly associated with the lean production concept. Hence we propose:

Proposition 4: There is an association between stages of evolution and performance.

The longitudinal nature of the data that we analyze enables us to test our four propositions and thus explore whether the integration of core lean HRM and OM practices in British manufacturing may be linked to sustainable productivity.

3. The empirical study

3.1 The data

We use company-level data from the Institute of Work Psychology (University of Sheffield) Modern Management Practices Survey Series. The dataset, as described by Birdi et al. (2008: 479–80), was constructed by matching the evidence from three surveys on the use of management practices to yearly audited records of company data that include a measure of performance. The surveys established the use of practices as well as when they were implemented, and were based on interviews with either the company's managing director or a senior representative responsible for HRM or production.

During these interviews, a definition of working practices was given, which was formulated from literature reviews, focus groups and pilot studies. Respondents were asked whether and how extensively the practice was used across the company and, if so, the year it was introduced. The descriptions of the practices that were common to all surveys in the series, as relayed to the interviewees, are listed in table 1 of Birdi et al. (2008: 480) and are:

- Empowerment: Passing considerable responsibility for operational management to individuals or teams (rather than keeping all decision-making at the managerial level).
- Integrated computer-based technology (ICT): Linking together computerized equipment to enable enhanced integration (such as CAD/CAM, computer-integrated manufacturing and flexible manufacturing systems).
- Just-in-time production (JIT): Making products or providing services in direct response to internal or external customer demands (rather than building in advance to maintain stock levels).
- Learning culture, which Birdi et al. (2008) relabeled "extensive training": Providing a range of development opportunities for all employees (rather than training people occasionally to meet specific needs).

- Supply-chain partnering: Developing strategic alliances and long-term relationships with suppliers and customers (rather than negotiating on a short-term basis).
- Team-based work: Placing employees into teams with their own responsibilities and giving them the freedom to allocate work among team members (rather than having everyone work as individuals).
- Total quality management (TQM): Seeking continuous change to improve quality and making all staff responsible for the quality of their work. (Such practices include Kaizen and continuous improvement.)

In 1996, these practices were identified as the most popular in the lean management practitioner literature and were estimated to be implemented in at least half of the UK's manufacturing companies (Waterson, Clegg, Bolden, Pepper, Warr and Wall, 1999), where their combined use was pioneered in the early 1990s by Japanese transplants and firms directly competing with or supplying them (Wood, 1996). Together with the HRM practices, they are also included within elements that define total quality management as a philosophy (Dean and Bowen, 1994). All seven practices appear in most accounts of lean production (e.g. Hopp and Spearman, 2004; Parker, 2003; Shah and Ward, 2003; Womack et al., 1990) and have been linked to descriptions of the Toyota Production System (e.g. Spear and Bowen, 1999). They represent two (supplier-related and internally related) of the three underlying constructs identified by Shah and Ward (2007) in their comprehensive investigation on what constitutes lean production. Individually, TQM, JIT and ICT were core to integrated manufacturing technology centers (Snell and Dean, 1992, 1994) or the Toyota Production System (Ohno, 1988) and were considered in studies of JIT manufacturing (e.g. Fullerton et al., 2003, Koufteros and Vonderembse, 1998). The data, however, does not cover the involvement of customers or TPM (Total Preventive Maintenance – Cua et al., 2001; Shah and Ward, 2003, 2007), which was only included in the 1996 survey where it was rarely used. Other HRM practices in the survey series (appraisal, selection procedures and reward schemes) were absent in most years and their link

with employee involvement remains questionable (Beer, Spector, Lawrence, Mills and Walton, 1984; de Menezes and Wood, 2006).

Birdi et al. (2008) checked the consistency between the reported years of introductions and the stated practice use in a sub-sample of over 200 companies for which they had additional data. Very few inconsistencies in the reported year of introduction of practices were found between surveys, in which case they opted for the most recent information. Their yearly data was then constructed, by combining the practice usage information from the three surveys with the information on when the practice had been introduced. The usage of each practice in each year of the study was then recorded as a binary indicator (1 if a firm was using a practice that year, otherwise 0). Only a small number of firms (1% of the total) had stopped using a practice within the period studied. Company-related yearly data (productivity, size of workforce, value of assets) were extracted 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.

Productivity, the performance variable in the dataset, is our dependent variable, and was measured as the logarithm of value-added derived profit and loss (operating profit, labor costs and depreciation), adjusted for GDP inflation so that the measure is standardized to 2001 prices. The focus on productivity as an index of performance is justified on grounds that “it should more directly reflect the impact of implementing management practices” (Birdi et al., 2008: 481); it represents a direct link between human capital and organizational performance (Datta, Guthrie and Wright, 2005) and is the key indicator of workforce performance (Delery and Shaw, 2001). Value-added is an important indicator of a company’s output because it evaluates a company’s efficiency relative to its input (Birdi et al., 2008; Kato and Morishima, 2002).

When testing Proposition 2 and thus considering the (yearly) association between the integrated use of practices and productivity, the models are controlled for: size of workforce (log number of employees), value of assets (log fixed assets adjusted for inflation), and time (accounting year). Finally, when examining the association between stages of adoption and

performance, we add initial productivity (value-added) to our controls, and measure time by the number of years from the starting accounting year. These controls are consistent with the Cobb-Douglas production function (Birdi et al., 2008: 481), as well as previous analysis of the diffusion of management practices (Bryson et al., 2007).

Our models, which are described in the next section, aim to fit all possible combinations of practice use in the data; if there were no missing observations, we could observe 128 (2^7) types of responses. Hence, we need as much information on practice usage as possible (see de Menezes, 1999, for the effect of sample sizes) and started with all 684 companies. However, the exclusion of missing values practice-by-practice resulted in inconsistent models over the years, so that we use the data from 448 companies that have complete information on all seven practices in every year of our study period (1980–2003). A total of 157 companies had complete information on all seven practices as well as productivity; the latter is unavailable for the first two years in the dataset, so when addressing the association with performance we are limited to this subset of 157 companies and the period from 1982 to 2003 (22 years). Yet this sample size is comparatively larger than other studies of the link with performance in the manufacturing industry that rely on data selected from far larger populations (e.g. Flynn et al., 1995; Kaynak, 2003; Powell, 1995). Our sample differs from Birdi et al. (2008), since they excluded the first two years because these lacked information on productivity thus leading to a total of 308 firms, but, depending on the practice or combination analyzed, their sample sizes vary from 122 to 284 firms.

3.2 Analysis procedure

Table 1 summarizes the steps, goals and methods that are involved in testing our four propositions, which are detailed below.

Table 1 approximately here

3.2.1 Assessing integration of practice-use and its link with performance

To test Propositions 1 and 2, we need to examine the association in practice use in all years studied and then analyze the link with performance. Our analysis differs from most of the literature, since lean production has often been treated solely as a set of management practices (e.g. Birdi et al., 2008; Li et al., 2005; Shah and Ward, 2007), which on their own or combined may be associated with performance. In which case, if x_i is a binary variable that indicates the use of practice i ($i=1$ to n), the link with performance can be assessed by the following model:

$Performance = \beta_0 + \beta_1 x_1 + \dots + \beta_n x_n + \beta_{n+1} C_1 + \dots + \beta_{n+k} C_K + \varepsilon$, where the C_{ks} ($k=1$ to K) are a set of control variables. In addition, if two or more practices are assumed to have a synergistic effect on performance, interactions or product-terms are added to the model. For example, when considering two practices, the model becomes:

$Performance = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_1 x_2 + \beta_{n+1} C_1 + \dots + \beta_{n+k} C_K + \varepsilon$. The estimated coefficients of the individual practices and their interaction term are then expected to be positive and to demonstrate that the effect of the combination is greater than that of individual practices.

By contrast, when we view lean production as a philosophy, in line with Proposition 1, practices co-exist due to this philosophy (latent variable) and can be measured by the common factor underlying the correlation of individual practices or elements. Integration implies that a common factor, which can be modeled as the latent variable that measures the philosophy, can be estimated. Moreover, when testing Proposition 2, it is the link between this factor and performance that should be examined, for example:

$Performance = \beta_0 + \beta_1 factor + \beta_{n+1} C_1 + \dots + \beta_{n+k} C_K + \varepsilon$, which in a longitudinal framework may be written as:

$$Performance_t = \beta_0 + \beta_{1t} factor_t + \beta_{n+1t} C_{1t} + \dots + \beta_{n+kt} C_{Kt} + \varepsilon_t. \quad (1)$$

Testing Proposition 1: Establishing evidence of integration and developing yearly measures of the construct. We need to assess whether a *factor* underlies the association between the seven practices in every year (t) of our data. If practices were used independently, we would

have no evidence of integration and Proposition 1 would be rejected. Hence, we first establish that there is significant correlation in practice use, so that we can estimate for each firm the value of this factor in the year. Since our practice data are binary variables, we use chi-square tests. Having established association, our second step is to determine whether this association is due to a common continuous factor. We therefore fit a logit-probit latent trait model that is analogous to the traditional factor model but is specifically for binary variables, as proposed by Bartholomew and Knott (1999: chapter 4) and used by de Menezes and Wood (2006) in their analysis of management practices. For brevity, we report that these fits were poor and from now on we consider models that assume the latent variable is categorical (discrete).

Latent class models were initially proposed by Lazarsfeld and Henry (1968) in order to identify homogeneous groups of individuals based on the correlation structure between several binary or categorical variables. Several variants of latent class models have been used in sociology to identify types of attitude structures from survey responses, in marketing to unveil consumer segments from demographic and preference variables and in management to identify management styles (DeSarbo, Di Benedetto, Jedidi and Song, 2006; Lewis, 2005; McCutcheon, 1987; Rost and Langeheine, 1997a; Wood and de Menezes, 1998). The standard latent class model assumes that binary indicator variables are associated because of discrete points (classes) in the latent space. In the absence of these classes, the indicator variables are no longer associated. Accordingly, we 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 or the size of a class, and $\mathbf{x}=(x_1, x_2, \dots, x_7)$ represent the response of a firm to the use of these seven 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:

$$f(\mathbf{x}) = \sum_{j=1}^K \eta_j \prod_{i=1}^p \pi_{ij}^{x_i} (1 - \pi_{ij}^{x_i})^{1-x_i} \quad (2)$$

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

$$h(j|\mathbf{x}) = \frac{\eta_j \prod_{i=1}^p \pi_{ij}^{x_i} (1 - \pi_{ij})^{1-x_i}}{f(\mathbf{x})}, \quad j=1, \dots, K \quad (3)$$

By maximizing the log-likelihood function, parameters (η_j s and π_{ij} s) are estimated. Multiple sets of random starting values are generally used to avoid local solutions. A firm is allocated to the class that it has the highest posterior probability (3) of belonging to. Consequently, in a latent class we have firms that do not necessarily make use of exactly the same subset of practices, but have the same probability of adopting each practice and as such have a similar approach to management.

A log-linear reformulation of this model, as shown by Rost and Langeheine (1997b), whose parameters are not probabilities and as such not restricted to the interval [0,1] enables restrictions to be applied to the parameters, the inclusion of predictors and more flexible inference for categorical indicator variables (Heinen, 1996; Vermunt, 1999). This reformulation has been adopted by Vermunt and Magidson (2005) in developing LatentGold 4.0, the software that we use here, to classify cases into homogeneous groups that they call latent class clusters.

If a categorical latent variable is responsible for the association in practice use, we can fit a latent class model to the data. LatentGold 4.0 is used to estimate the model parameters and allocate firms into latent class clusters for each year in the dataset. Standard goodness-of-fit and model selection statistics are then used to judge the number of latent class clusters that best fits the data. Residual correlations are analyzed in order to detect any dependency between pairs of practices (violation of the local independence assumption), which, if necessary, can then be modeled. Since the probabilities of a firm adopting each practice are estimated, given that it is in a cluster, we can also identify the characteristics of each cluster in terms of how firms are likely to use practices.

As we describe in the next section, we fit up to five latent classes per year and the best solutions imply either two- or three-classes; we opted for three. However, the yearly classification varied and we then restricted the models so that the probability of a firm using a

practice changes monotonically as we move along the sequence of latent class clusters, i.e.: $\pi_{ij} \geq \pi_{ij-1}$. In short, we estimate models that are known in the statistical literature as order-restricted latent classes (Goodman, 1974; Croon, 1990), which represent an intermediate stage between the latent trait model where the latent space is a continuum, as in factor analysis, and the standard latent class model described above. This procedure results in three ordered homogeneous clusters of firms per year and a firm is allocated to the cluster that it has the highest estimated probability of belonging to. In each cluster, the probabilities of a firm adopting a practice i , where $i=1$ to 7, is the same, and as specified these do not decrease from cluster 1 to 3.

Testing Proposition 2: Establishing the link between integration and performance. The association between cluster membership and productivity 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). Cluster 2, the medium-usage cluster, is chosen as the baseline, so that if there is a link, we would expect a positive coefficient for Cluster 3 and/or a negative coefficient for Cluster 1. Our model is the following:

$$productivity_{it} = \beta_0 + \beta_s Size_{it} + \beta_A Assets_{it} + \beta_t t + \beta_{Cl1} Cluster1_{it} + \beta_{Cl3} Cluster3_{it} + e_{it} \quad (4)$$

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 1 to 22 (1982 to 2003, since 1982 is 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 our model, as described in equation (4), and the baseline model is assessed 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 that our model has, relative to the baseline model).

3.2.2 Assessing evolution and its link with performance

Testing Proposition 3: Establishing the evidence of evolution and classifying firms according to the different stages. In order to establish the trajectory (evolution) of each practice, we estimate latent growth cluster models (latent class growth analysis or LCGA: Andruff, Carraro, Thompson, Gaudreau and Louvet, 2009; Jung and Wickrama, 2008; Muthén, 2001, 2004), using LatentGold 4.0 as described by Vermunt and Magidson (2005). These models are increasingly being used in social sciences and psychology with the aim of capturing information over time about inter-individual differences and intra-individual change (Nesselroade, 1991; Wang, 2007). In contrast to conventional growth models that would assume firms come from a single population and that a single growth trajectory can adequately approximate the entire population, LCGA enables the identification of homogeneous clusters of firms that describe similar growth trajectories of practice use.

We first examine the growth pattern of each practice separately, by using time (year) as a predictor of usage in a latent class growth model. The aim is to find the best model (correct number of latent classes) that describes the evolution of each practice. However, after attempting to model the growth using the 24 points in time, the results did not converge to unique solutions. Therefore, we divided the period 1980–2003 into five epochs of equal length as follows: epoch 0=1980–1984, epoch 1=1985–1989, 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 estimate latent class growth models for each individual practice: the dependent variable is the practice-use indicator ($x_i=0$ or 1) and the predictor is the epoch coded 0 to 4, as defined above. Practice-use indicators are binary variables and thus binary logistic regression models are estimated. For each practice, we fit up to five latent classes and choose the model with the lowest Bayesian Information Criterion (BIC) that describes the growth or trajectory for

each practice. A mean growth curve is estimated for each class. We then use the identified growth classes as inputs to a second latent class model, whose classification summarizes the overall evolution of the seven practices. In short, this is a two-stage process that leads to a single classification of firms (trajectory class) based on the diffusion of the seven practices over the 24 years.

Testing Proposition 4: Establishing the link between stages of adoption and performance. Finally, we investigate whether the evolution is associated with firm performance, by examining productivity in the last available accounting year as a function of trajectory class that categorizes firms according to the identified stages of adopting (integrating) practices. A General Linear Model is estimated using SPSS14, where the dependent variable is final performance and the covariates are initial productivity, final company size, final fixed assets and accounting period. The trajectory class is the categorical predictor. We also estimate an alternative model, as a validity check, where the dependent variable is an average of productivity in the last two years and the initial productivity is replaced by its average in the two initial years.

4. Empirical Results

4.1 The link between integration and performance

4.1.2 Establishing the evidence of integration

Testing for association in practice use. Chi-square tests of the cross-tabulations of the seven practices for the 24 years showed that independency was generally rejected (P-values < 0.05). We also observed that in 1980, 14% of firms reported using one or more OM practice and only 9% reported using one or more HRM practice; by 2002 these figures had grown to 99% and 98% respectively. In order to confirm that HRM practices were not being 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-values ≤ 0.002). There is no evidence that firms emphasized a type of practice, or that two separate clusters representing HRM and OM practices are likely to emerge from these data. In short, there is significant correlation in practice use over the 24 years.

Estimating the underlying construct: Identifying yearly latent class clusters or homogeneous groups of firms (1980–2003). As the data did not fit either a one- or two-factor latent trait model, and failed the goodness-of-fit tests described by Bartholomew, Steele, Moustaki and Galbraith (2002: 184–188), there is no evidence of a continuous common factor. We therefore tested for a discrete common factor, as outlined in Table 1, and initially considered up to five latent classes – $K=2$ to 5 in (2). However, some models resulted in multiple solutions, indicating that either sample sizes were not sufficiently large to capture the detailed patterns that stem from large models or that fewer homogeneous clusters are present in the data. Hence, we estimated two- and three-latent class models (up to 23 parameters in a model) in each year, and used model selection criteria to decide 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. It can be seen in the first decade of the period that two- and three-latent cluster solutions fit the data equally well. From 1989, 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. Yet the ordering of clusters oscillated between years. In order to achieve consistency year to year, we use order-restricted models that, as described in the previous section, constrain the probabilities of using a practice in each class so that they do not decrease. Consequently, the latent variable that we estimate is ordinal.

~Figure 1~

Although the three-class solution might 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 concentrate on three-class models, which are specified so that the first cluster makes the minimum use of practices and the third the maximum use. All estimated models are identifiable (converge to unique solutions) and satisfy the goodness-of-fit criteria, thus Proposition 1 is supported by the data.

Our results are summarized 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 (estimated) 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. Firms in Cluster 3 appear to be the innovators, who are then followed by the others. At the start of the study period, Cluster 3 firms had already adopted an average of about four different practices, which increased to just above six at the end of the period, suggesting that most firms in this cluster use all seven practices in the final year. As Figure 2b indicates, Cluster 3 was initially quite small, but increased significantly in the 1990s so 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 observable for Cluster 3.

Firms in Cluster 1 are characterized by a consistently low use of practices, which only increases by around the year 2000. This cluster comprises about 90% of the firms at the start of the study period, but membership declined steadily. By contrast, Cluster 2, which contains firms with an intermediate usage of practices (an average use of two practices until 1990), increased in size up to 2000, and then decreased, such that by 2001 the data could be reasonably represented by a high usage and a low usage group.

The observed frequencies of using a practice and the estimated probabilities of using a practice vary significantly from cluster to cluster (see Figure 2c). Overall, JIT is used less and is not used in Cluster 1; but in more recent years, the estimated likelihood of its use, according to the latent class models, increased significantly in Clusters 2 and 3 (Figure 2d – probability of usage is approximately 0.70).

Figure 2d shows the evolution of the estimated probability of using each practice if a firm belongs to a cluster over the years. Clusters 2 and 3 are closer with regards to the estimated probabilities of using OM practices, whereas Clusters 1 and 2 are closer with respect to their likelihood of making use of empowerment in the early and late years. The relative gaps between each cluster in the figures suggest that ICT and supply-chain partnering discriminate between Clusters 1 and 2, whereas empowerment and teamwork discriminate between Clusters 2 and 3. All figures indicate that firms in Cluster 3 adopt an integrated management approach and are more likely to mirror those that have been described in the literature as early implementers. If there were benefits from having such an approach, we would expect this group of firms to outperform the others.

Testing Proposition 2: The link between cluster membership and performance (1982–2003). The association between productivity, our performance measure, 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;

its fit statistics are: $-2\log LL=1775$, $BIC=1814$, which show a significant improvement from a null model that estimates the intercept ($-2\log LL=5195$, $BIC=5210$). 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 summarized in Table 2. This model is not an improvement in quality of fit ($-2\log LL=1779$, $BIC=1818$) when compared to our baseline growth model, but indicates that belonging to the high-usage cluster (Cluster 3) is positively associated with performance ($t=2.35$, $p=0.019$), while belonging to the low-usage cluster is not ($t=-0.44$, $p=0.66$). That is, a high-usage firm outperforms medium-usage firms, though there is no difference between those within low- and medium-usage groups nor is cluster membership per se a strong predictor of productivity.

The lack of difference in productivity within the two lower clusters 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 use in each cluster, we might conclude that Cluster 3 is the only one making a fully integrated use of practices. Indeed, this is confirmed when we consider the estimated probabilities of using each practice if a firm is in Cluster 3 that resulted from the yearly models, as illustrated in Table 3. We observe that not only the estimated size of Cluster 3 significantly increases in the period, but also that by the year 2003 all seven practices are very likely to be adopted within this group of firms. All in all, those that made a more integrated use of practices are also more likely to be high performers. These results may indicate support for Propositions 3 and 4, which we now formally test by following the steps that were described in Table 1.

~Tables 2 and 3~

4.2 Assessing the link between stages of adoption and performance

Testing for Proposition 3: Establishing the evidence of evolution and classifying firms according to the different stages. We first estimated growth models for each practice separately.

For TQM, empowerment and ICT, the best latent class growth model is a three-class model, and for JIT, learning culture, supply-chain partnership and teamwork it is a four-class model. The latent class growth models are summarized in Table A1 (Appendix), where we report the estimated regression coefficients, the quality of fit of the model and the size for each class per practice. These describe the different growth curves per practice that were identified; a higher coefficient for epoch indicates higher growth. For learning culture and supply-chain partnership, the fourth class contained less than 1% of cases, so we also adopt three-class solutions for these practices. For JIT and teamwork, four classes were identified whose sizes were greater than 5%; we kept the 4-class solution, though we note that in both cases one of the growth classes explains a very small proportion of the variance (low r-square). These results indicate that there are three clearly identifiable stages in the evolution of these practices.

Identifying firms according to stages of evolution of an integrated approach. Our next step was to classify the firms based on the growth models. The indicators for clustering were the seven growth class membership variables that are categorical variables ranging from 1 to 4 in the case of JIT and teamwork, or 1 to 3 for all other practices. In order to identify the number of trajectory clusters across all practices, models with up to five latent classes were estimated. Goodness-of-fit chi-square statistics were non-significant ($p=1.00$) for models with more than three latent classes. Three clusters are sufficient to describe the whole data and companies can be classified in three trajectory clusters that describe the evolution across the seven practices. The classification error rate for this model is 7%, which is quite good and we have support for Proposition 3.

Results are summarized in Table 4, which shows the size of each trajectory cluster and the probabilities of belonging to each of the practice growth classes when a firm is within a trajectory cluster. According to this table, the composition of each trajectory cluster in relation to the growth classes of each practice can be inferred. For example, firms in the second trajectory cluster are more likely to belong to Growth class 1 for empowerment (probability =

87% when Growth class is equal to 1 for empowerment), which corresponds to companies that experienced the highest growth for empowerment since its regression coefficient for epoch in Table A1 is equal to 6.85 and is the highest among the three growth classes. Similarly, it can be seen that higher growth in JIT use (Growth Class 2) is also associated with a higher likelihood of company being in the second trajectory cluster (probability = 0.63).

~Table 4~

Yet, in line with Proposition 3 and aiming to test Proposition 4, we focus on the evolution across all practices. By plotting the observed practice use per trajectory cluster, as shown in Figure 3, we have a clearer picture of the year-on-year evolution that enables the identification of the three adoption stages.

~Figure 3~

Firms in Cluster 3 are early adopters who tend to make an integrated use of practices early on, the smallest group (12.6% of the sample, as shown in Table 4). In this cluster, however, 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. These are firms that we will call intermediate adopters, based on their initial status. In fact, by the end of the study period, firms in this cluster have a higher estimated 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 their 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. We will refer to firms in Cluster 1 as late adopters.

Testing Proposition 4: Establishing the link between stages of adoption and performance. We investigated a possible effect of the three trajectories on performance, by examining productivity in the last available accounting year as a function of the trajectory class,

controlling for company size, fixed assets in the final accounting year, productivity in the initial (first available) accounting year, and the number of years (accounting period) between the initial and final accounting years. A general linear model with final productivity as the dependent variable was estimated. Initial productivity, workforce size, final assets and accounting period were entered as covariates, and the trajectory class was the categorical predictor.

~Table 5~

The results are shown in Table 5, 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. Pairwise comparison tests showed that early adopters significantly outperform both late and intermediate adopters ($p < 0.05$) in the final accounting year, but there is no significant difference between late and intermediate adopters. In spite of the similarity in performance between late and intermediate adopters, we have an indication that early adoption is beneficial to the firm.

These results were confirmed by a similar model where the initial productivity was measured as the average of the first two available years, and similarly the final productivity 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 (and average final) productivity. Given that intermediate adopters experienced rapid growth and by the end of the period studied make a similar or even greater usage of the practices than early adopters (as shown in Figure 3), this productivity differential supports Proposition 4. Furthermore, it suggests first-movers' advantage, which may reflect the continuous improvement achieved through a longer period of integrating practices.

5. Discussion

Our review of the literature has shown that many studies have addressed the potential gains from combining two or more elements of lean production, and that often such combinations entailed both OM and HRM practices. We therefore expect a significant correlation in the use of practices and thus a focus on separate elements may hide the potential outcomes from integration. Indeed, the evidence from case studies on the successes of quality management and lean production suggest that integrating OM and HRM practices is crucial (e.g. Scherrer-Rathje, Boyle and Deflorin, 2009; Terziovski, Sohal and Samson, 1996). Yet few authors have empirically addressed the integration of management practices and even fewer its link with productivity.

In the present study, we observed that the use of the seven practices evolved in a similar fashion and three homogeneous groups that described three levels of usage were identified for each of the 24 years studied. The assumption that practices are only manifest of a latent philosophy and that they would be independent in the absence of this philosophy was supported by the data. The choice of practices is not driven by expectations on the performance of specific combinations but by having an integrated system in place that reflects a managerial philosophy. Hence, the focus switches from potential efficient bundles of practices to this unobserved philosophy or management approach.

The implication for the practitioner is that there are no magical solutions or quick-fixes; the philosophy needs to be in place. Indeed, this may not be surprising when we consider how much academics and practitioners have written about Toyota. The challenge remains to fully embrace the philosophy, be it quality management, integrated manufacturing, just-in-time manufacturing or lean production. In fact, the need for integration between OM and HRM has been acknowledged in descriptions of success as well as failures of quality management strategies. Boudreau, Hopp, McClain and Thomas (2003) argued that in spite of a practical need for integration because they are fundamentally related, the disciplines of HRM and OM tend to be taught, researched and practiced separately, often drawing on distinct disciplinary

foundations. Consequently, more can be learned from addressing the interface, since OM and HRM can explain and moderate the effect of each other, in which case integration is crucial for competitive advantage.

Given that we had no evidence of a continuous latent variable that would measure the underlying philosophy, latent class models enabled the identification of clusters and significantly reduced the number of performance equations that were analyzed when compared to previous studies on synergies, without the need for either arbitrary criteria or pre-specified bundles. This type of model may also capture the non-linear association between practice and performance that has often been mentioned. The analysis can be extended to ordinal or continuous manifest variables, allowing for different levels of measurements and restrictions to be added. If necessary, the assumption that the correlation between practices is only due to the philosophy being measured can be relaxed. Hence, latent class models are powerful clustering tools that can be used in future studies on large samples. In fact, if the pattern of low versus high implementation that has been observed in the literature persists, such models may be more robust than factor analysis when analyzing data that measure the extent of use. This is particularly important when addressing the link with performance, as recent empirical work has used structural equation models, which assume that the data are reasonably well distributed.

We observed that some firms moved between clusters so that in the final years only two clusters might as well have been identified. Indeed, this pattern, which is observed after 2000, is consistent with previous research where samples were generally split into two groups: basic–advanced users, early–late implementers. In the present study, however, this pattern stems from an integrated (correlated) use of practices and its evolution, and not from an arbitrary cutting-point (e.g. use of 2/3 of practices at least 50% of times – Callen et al., 2003) or quality criterion (e.g. award winners). It is possible that such a pattern might have resulted from focusing on the set of the most widely used practices in a single industry sector, because similarities between firms could have facilitated the spread of practices and thus favor a two-way classification: use,

no-use. Although the lower-usage cluster became smaller with time, some firms have lagged behind the majority. In which case, they are either more resistant to innovations or lack the investment capacity. Given our data, we are unable to identify factors that could explain this perceived stagnation and we look forward to further work on different industries with a wider set of practices and firm characteristics to clarify these findings.

Our results indicate that high usage and integration of OM and HRM practices are linked with productivity. They support previous work on similar data (Birdi et al., 2008), which concluded that expectations based on the lean production concept were supported by the data: pairwise combinations of the OM and HRM practices tended to be positively associated with productivity, while OM practices on their own were not; supply-chain partnering positively interacted with the other OM practices; and teamwork interacted with most practices. In all, Birdi and his colleagues concluded that adopting empowerment and extensive training was the key to productivity. In our view, the implication that empowerment alone is best practice is misleading, since a clear operational focus can be critical to its success. Nonetheless, they also argued that “there is no practice that does not appear to have some effect when combined with one or more practices” (Birdi et al., 2008: 496). We cannot directly compare the size of effects, due to sampling variations in the models. There is no evidence, according to them, to suggest that firms using any of the seven practices without an individual effect on productivity should stop adopting them. Hence, they seem to have recommended that practices should be used as a package, in spite of some having larger effects. In our results, as indicated by the gaps between the curves of each cluster in Figure 2d, the estimated probabilities of adopting practices in different clusters suggest that empowerment and teamwork may discriminate between medium- and high-usage firms, whereas supply-chain partnership may discriminate at the bottom end. As matter of fact, when we consider the higher-usage that we found to be the most productive cluster, as illustrated in Table 3 in the last year studied (2003), all firms had introduced

empowerment and teamwork, while 15.6% had not introduced JIT and 4.6% had not introduced supply-chain partnering.

We specifically examined whether there were sustainable effects by modeling the stages of adoption. Based on the diffusion of each practice in the sample, we classified firms according to when they adopted practices. The data unveiled three groups: early adopters, intermediate adopters and late adopters. At the end of the period, intermediate adopters had not only caught up with early adopters but were even making more use of practices, as we illustrate in table A2 where the actual use of practice by the different groups in different years is shown. In contrast with 1990, when late and intermediate adopters rarely used the practices (median number of practices used were respectively 0 and 1), in 2003 more practices were widespread in these groups. Nevertheless, early adopters, a relatively small group (12.28% of the sample), outperformed the others. This final result supports the initial claims that led to the spread of quality management as a philosophy, which is that a cohesive management system and continuous improvement can become sources of competitive advantage. It could be that some of the early adopters in our sample were initially high performers, but since we controlled for initial productivity and considered alternative models, we do have an indication of potential first-mover's advantage and long-lasting effects. It seems that benefits are sustainable over the long term and thus we were unable to observe the productivity gains of the intermediate adopters because their use of practices only caught up with early adopters near the end of the period studied. This should be further investigated within the more encompassing concept of lean production, and preferably beyond manufacturing. In which case, we would like to stress the need for future longitudinal studies that include all elements of lean production, other factors that may influence the learning experience, and the diffusion of management practices.

6. Conclusion

This is the first longitudinal study on the integration between OM and HRM practices and firm performance in British manufacturing. It contrasts with previous work, which tended to investigate potential effects of either individual practices or specific combinations, and focuses on the association between practices and its link with productivity.

We argued that the integration of practices would reflect a managerial approach that combines OM and HRM, as advocated in the quality management and lean production literatures. Consequently, it is the integration of practices that would have the ability to achieve multiple goals and result in superior firm performance. We used ordered restricted latent class models to identify homogeneous clusters of firms and established a positive link with performance. In addition, our analysis of the diffusion of each practice resulted in an alternative classification that describes three stages of adoption, and we found that earlier integration is indeed associated with performance. Overall, the benefits appear to be sustainable. An integrated managerial philosophy is potentially a source of competitive advantage, highlighting the importance of continuous improvement and learning that is often allied to the lean production concept.

We lack information as to the extent of the use of practices and rely on single-item measures, but generally our results are quite positive and give us insights into the potential evolution of lean production in British manufacturing. Moreover, we rely on just one measure of performance – productivity – though it may be more reliable than financial performance indices, which are more likely to reflect several economic factors that cannot be controlled by any individual company and thus lead to far more complex models. We regret not having access to data on quality and lead-time, which in our view are key outcomes.

An additional limitation is the focus on core practices that are the most used in British manufacturing and as such by the end of the study period are widespread in the sample. Yet our results of a positive link between an integrated use of OM and HRM practices and performance are consistent with more recent findings by academics and consultants based on a cross-section

of 730 manufacturing firms in France, Germany, the UK and the US (Bloom, Dorgan, Dowdy, Rippin and Van Reenen, 2005). An index of 18 practices (OM and HRM) was positively associated with productivity, return on capital employed, sales per employee, sales growth and growth in market share. These findings should encourage future work on more detailed data that would allow for multi-item measures of a wider range of practices and implementation.

In all, this research introduces a framework and statistical models that are not traditionally used in empirical analysis of potential performance effects, but are fit to address the integration of management practices in large samples. It gives evidence into the evolution of core OM and HRM practices in British manufacturing and shows that integration, early adoption and continuous improvement may be linked to organizational performance.

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Figure 1: Akaike Criterion – Latent Class Models

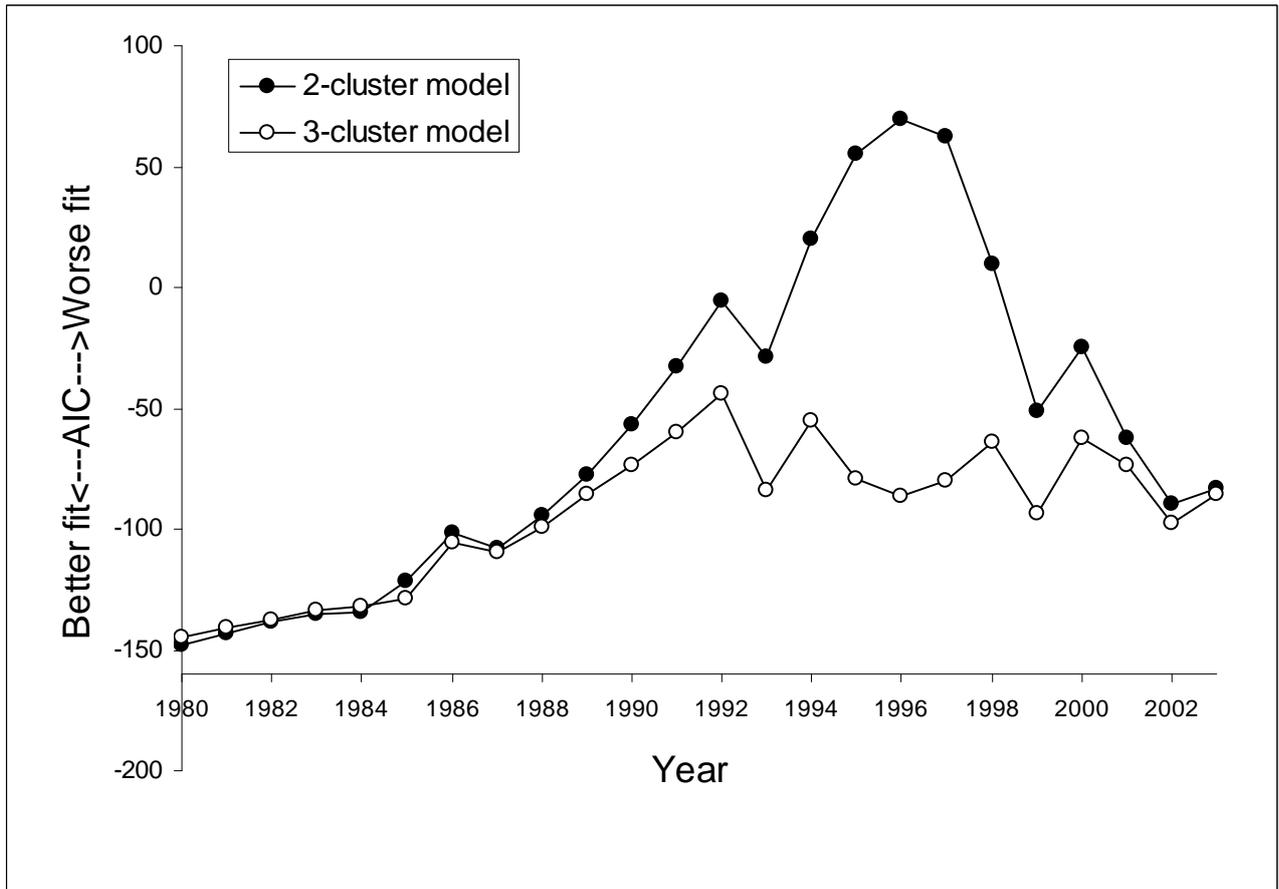


Figure 2a. Evolution of practice usage

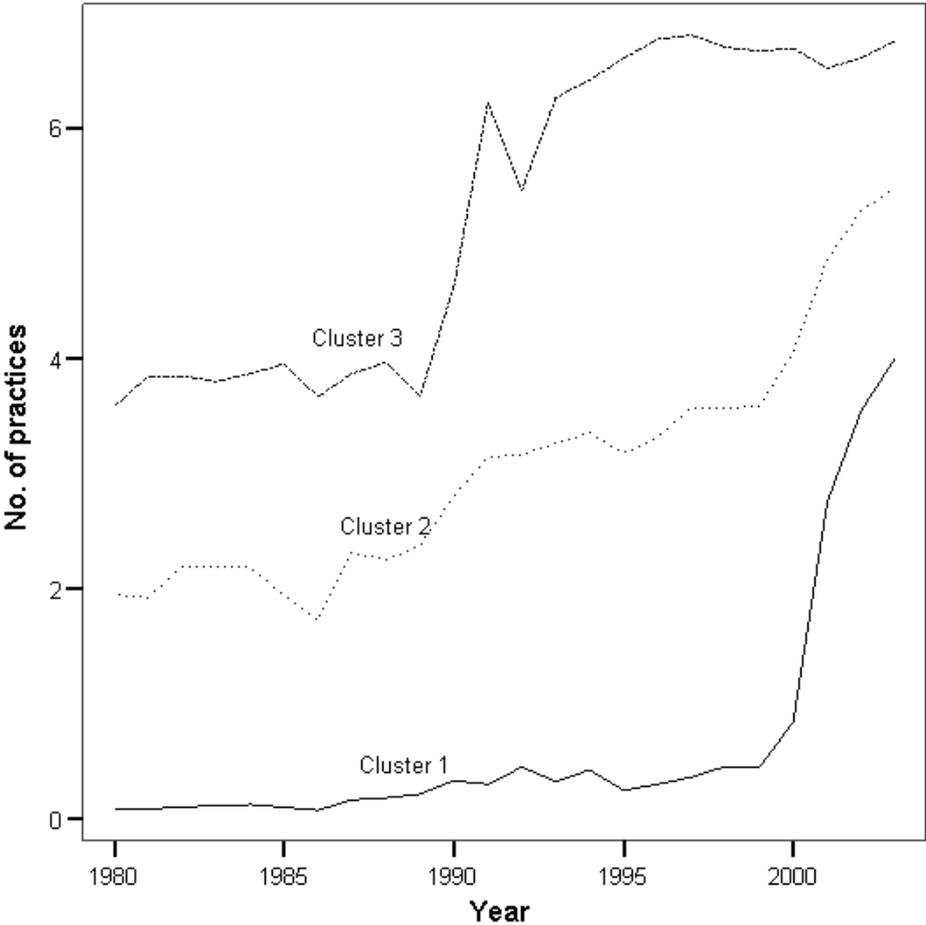


Figure 2b: Evolution of cluster membership



Figure 2c: Frequency of practice use by cluster and year

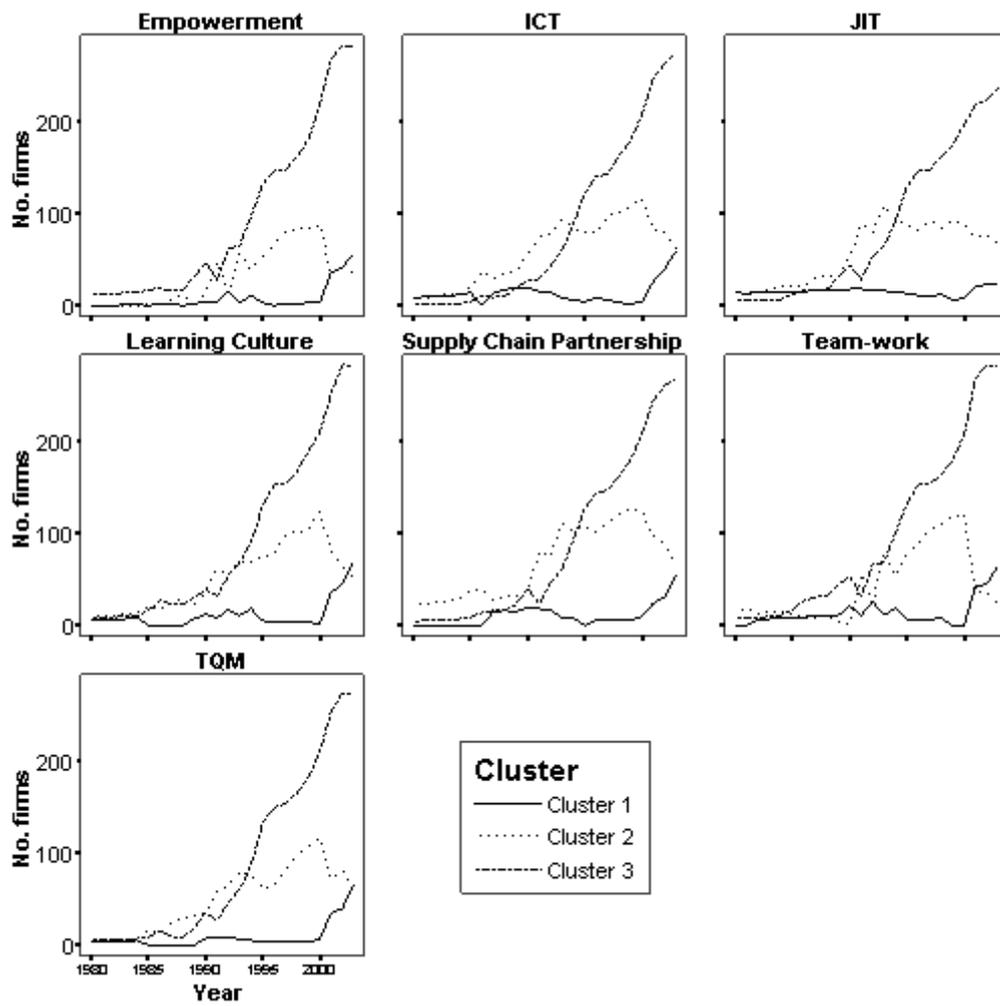


Figure 2d: Estimated probability of practice-use per Cluster

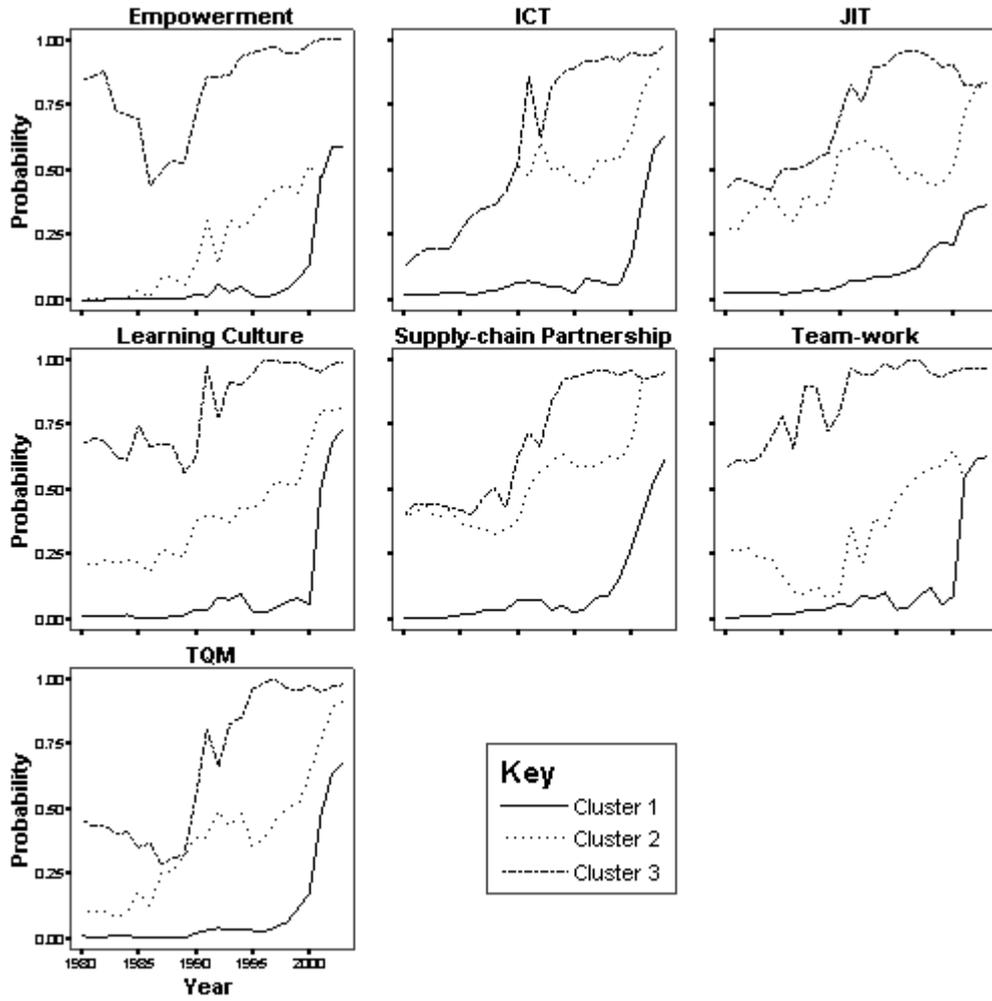


Figure 3: Practice evolution trajectories: Proportion of firms using each practice

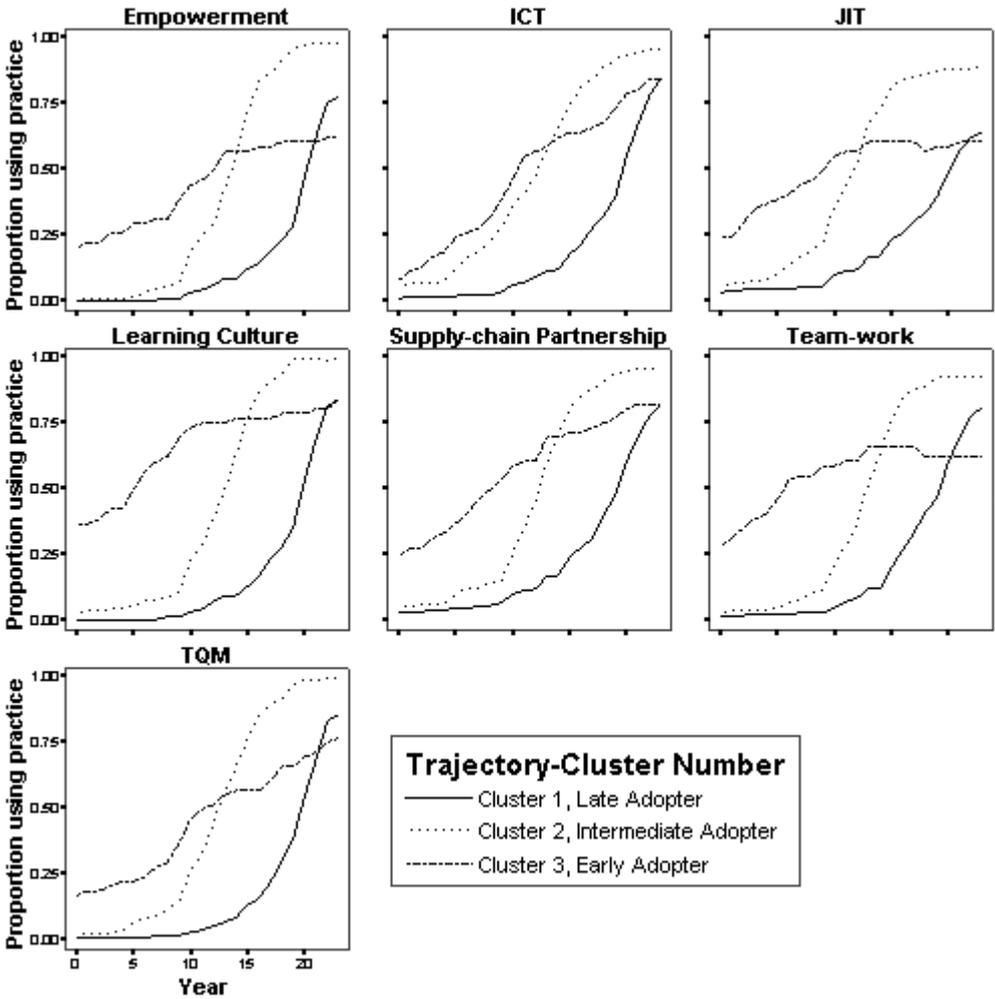


Table 1: Methodological Summary

Steps in Testing Propositions	Goal	Method
<p>Proposition 1 For each year of practice use data: 1. Test for association in practice use 2. Test for a common factor (latent variable that measures the integrated approach)</p>	<p>Establish evidence of integration and develop yearly measures Examine evidence for integration of OM and HRM practices Estimate the underlying construct (common factor) to be analyzed: Continuous Discrete (clusters of firms that similarly integrate practices)</p>	<p>Chi-square tests of independence Latent trait model (Bartholomew et al, 2002: 175–206)¹ Latent class analysis (McCutcheon, 1987)²</p>
<p>Proposition 2 Test for a link between extent of integration and productivity</p>	<p>Establish link between integration and performance Continuous Estimate equation 1 if the common factor is continuous; Discrete Assess significance and identify the sign of the estimated coefficients for the common factor (cluster membership). In our case, a significant positive coefficient for the high usage cluster (or a significant negative coefficient for the low-usage cluster) indicates a positive link between combined practice use (integration) and productivity.</p>	<p>Linear two-level model (Goldstein, 2003) Level 1= firm, Level 2= time Dependent variable= productivity</p>
<p>Proposition 3 1. Estimate the evolution of each practice 2. Estimate the underlying evolution of all practices, using results from the previous stage as input</p>	<p>Establish evidence of evolution and classify firms according to their different stages Identify the evolutionary stages of each practice Identify stages of evolution of an integrated approach</p>	<p>Latent class growth analysis (Andruff et al, 2009)⁴ Latent class analysis</p>
<p>Proposition 4 Test for a link between stages of adoption and productivity</p>	<p>Establish a link between the identified stages and performance Estimate the linear model and assess the significance of the adoption stages</p>	<p>Linear model (GLM or OLS) Independent variable = evolution (trajectory class) Dependent variable = productivity</p>

¹ If the extent of practice use were available rather than binary indicators of practice use, standard factor analysis would be used.

² If latent variable is ordinal, estimate an order-restricted model.

³ If latent variable is ordinal, estimate an order-restricted model.

⁴ Time (t=1 to 24) would have been the predictor of usage; we were unable to estimate the model and thus divided the 24 years in equal lengths (epochs) that we use as predictors.

Table 2: Cluster Membership and Productivity – 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	0.1	0.016	6.47**	0.1	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 – low usage				-0.01	0.027	-0.44
Cluster 3 – high usage				0.06	0.025	2.35*

* $p \leq .05$

** $p \leq .01$

Dependent variable: log (Value-added)

Table 3: High-Usage Cluster 3 – Estimated Probabilities of Practice Use and Size

Practice	Year					
	1980	1985	1990	1995	2000	2003
Empowerment	0.84	0.70	0.71	0.95	0.98	1.00
ICT	0.13	0.26	0.52	0.89	0.95	1.00
JIT	0.42	0.50	0.70	0.94	0.90	0.84
Learning Culture	0.67	0.74	0.62	0.94	0.96	0.99
Supply-chain	0.39	0.42	0.62	0.93	0.96	0.95
Teamwork	0.57	0.78	0.79	0.96	0.95	0.97
TQM	0.46	0.35	0.54	0.96	0.97	0.98
Size of Cluster 3	0.03	0.05	0.14	0.30	0.44	0.60

Table 4: Final Three-Class Solution based on the Evolution of Practice Use

	Cluster (Trajectory) Cluster Size	Late adopter 46.8%	Intermediate adopter 40.6%	Early adopter 12.6%
Management practice	Growth class	Probability ^a		
Empowerment	1	0.29	0.87	0.25
	2	0.69	0.06	0.40
	3	0.01	0.07	0.36
ICT	1	0.36	0.64	0.39
	2	0.61	0.08	0.25
	3	0.03	0.28	0.36
JIT	1	0.61	0.10	0.37
	2	0.12	0.63	0.25
	3	0.23	0.20	0.02
	4	0.04	0.07	0.36
Learning Culture	1	0.35	0.88	0.12
	2	0.64	0.02	0.23
	3	0.01	0.10	0.65
Supply-chain	1	0.42	0.79	0.26
	2	0.53	0.06	0.22
	3	0.05	0.15	0.52
Teamwork	1	0.70	0.38	0.01
	2	0.11	0.55	0.26
	3	0.17	0.03	0.36
	4	0.02	0.04	0.37
TQM	1	0.37	0.82	0.31
	2	0.62	0.04	0.33
	3	0.02	0.15	0.36

^aProbability of belonging to growth class conditional upon Cluster membership.

Table 5: Productivity and the Overall Evolution of Practice Use

Source	Mean square	F	Partial Eta-square (%)
Corrected Model	41.3	181.8***	87.9
Intercept	70.7	311.3***	67.5
Initial Productivity	0.1	0.6	0.4
Value of assets	2.2	9.8**	6.1
Final size of workforce	45.9	202.0***	57.4
Time (accounting year)	0.0	0.0	0.0
Trajectory class	0.8	3.3*	4.2
Error	0.2		

Note: Dependent variable is log (Value-added) in the final accounting year. R-Sq=.88.

*** p<.001 ** p≤.01 *p≤.05

Appendix - Table A1: Latent Class Growth Models

Practice	Class	Estimated Regression Coefficients		R-square	Class Size
		Intercept	Epoch		
Empowerment	1	0.65	6.85	0.80	50.40%
	2	0.43	3.68	0.51	40.60%
	3	-1.08	1.63	0.40	9.00%
ICT	1	0.46	3.82	0.77	48.50%
	2	0.13	5.89	0.64	34.50%
	3	-0.59	4.88	0.59	17.00%
JIT	1	0.36	5.08	0.19	32.40%
	2	0.30	6.48	0.82	30.40%
	3	0.21	2.79	0.72	27.80%
	4	-0.87	-2.52	0.06	9.40%
Learning Culture	1	0.52	6.96	0.80	48.80%
	2	0.28	2.57	0.54	38.20%
	3	-0.80	4.24	0.41	13.00%
Supply-chain	1	0.66	3.95	0.78	55.80%
	2	0.03	5.56	0.53	29.60%
	3	-0.68	4.39	0.39	14.60%
Teamwork	1	0.94	3.16	0.71	50.30%
	2	0.38	6.43	0.86	28.50%
	3	-0.35	1.42	0.01	13.80%
	4	-0.97	-2.84	0.10	7.40%
TQM	1	0.60	6.98	0.80	51.10%
	2	0.30	3.02	0.57	37.60%
	3	-0.90	4.46	0.58	11.30%

Table A2: Observed Percentage of Practice Use per Type of Adopter in Three Years of the Study

Practice	1980			1990			2003		
	Late	Intermediate	Early	Late	Intermediate	Early	Late	Intermediate	Early
Empowerment	0.00	2.72	20.00	2.87	18.48	43.64	77.03	97.28	69.09
ICT	0.48	4.89	7.27	5.74	35.87	45.45	84.21	95.65	87.27
JIT	2.87	5.98	23.64	9.57	35.33	54.55	63.64	88.04	65.45
Learning Culture	0.00	2.72	36.36	2.87	22.16	72.73	83.73	98.91	85.45
Supply-chain partnering	2.39	4.89	23.64	9.57	17.39	81.82	81.34	95.11	83.64
Teamwork	1.44	2.72	27.27	4.31	19.57	58.18	81.82	91.85	67.27
TQM	0.48	2.17	16.36	2.39	13.59	69.09	85.17	98.91	78.18
Mean No. of Practices	0.08	0.24	1.55	0.37	1.82	3.78	5.55	6.65	6
Median No. of Practices	0	0	1	0	1	4	6	7	6
Minimum No. of Practices	0	0	0	0	0	1	2	4	4
Maximum No. of Practices	2	3	6	4	7	7	7	7	7

Sample Size = 448; No. of Early Adopters = 55; No. of Intermediate Adopters = 184; No. of Late Adopters = 209.