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New human resource management practices, complementarities and the impact on innovation performance

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In this paper, we take our theoretical point of departure in recent work in organisational economics on *systems* of human resource management (HRM) practices. We develop the argument that just as complementarities between new HRM practices influence financial performance positively, there are theoretical reasons for expecting them also to influence innovation performance positively. We examine this overall hypothesis by estimating an empirical model of innovation performance, using data from a Danish survey of 1,900 business firms. Using principal component analysis, we identify two HRM systems which are conducive to innovation. In the first one, seven of our nine HRM variables matter (almost) equally for the ability to innovate. The second system is dominated by firm-internal and firm-external training. Of the total of nine sectors that we consider, we find that the four manufacturing sectors correlate with the first system. Firms belonging to wholesale trade and to the ICT intensive service sectors tend to be associated with the second system.

Key words: Innovation, Human resource management practices, Organisational complementarities, Evolutionary economics
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1. Introduction: new human resource management practices and innovation

The ongoing restructuring of management and organisation practices designed to cope with an increasingly complex and rapidly changing knowledge-based economy has received increasing attention from scholars from a diversity of disciplines and fields (Bowman and Singh, 1993; Huselid, 1995; Guest, 1997; Zenger and Hesterly, 1997). In particular, much attention has been given to the restructuring of the employment relation in the form of changed human resource management (HRM) practices that has accompanied the

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emergence of firms specialised for competing in dynamic, information-rich environments (Ichniowski *et al.*, 1996). These practices encompass various types of team-based organisation, continuous (often internal and team-based) learning, decentralisation of decision rights and incentives, systems for mobilising employee proposals for improvements, quality circles, emphasis on internal knowledge dissemination, etc. (Lado and Wilson, 1994; Zenger and Hesterly, 1997; Mendelson and Pillai, 1999).

While many of these new practices may not, strictly speaking, be entirely novel, some of the broad generalisations about new HRM practices refer to trends that appear to be truly recent (Osterman, 2000). Thus, new HRM practices appear to follow a steep diffusion curve (*ibid.*), and they tend to be adopted in a system-like manner rather than as individual components (Ichniowski *et al.*, 1997; Laursen and Mahnke, 2001). Moreover, there are some indications that they tend to be associated with high innovation performance (Mendelson and Pillai, 1999; Michie and Sheehan, 1999). It is these emerging 'stylised facts' and particularly the latter two, that we try to address theoretically and empirically and to substantiate in this paper.

The increased attention paid to new HRM practices has been particularly prevalent in the fields of strategic management, HRM and, increasingly, the economics of organisation. For example, strategy scholars have argued that human resources are particularly likely to be sources of sustained competitive advantage and that HRM practices should therefore be central to strategy (Barney, 1991, 1995; Lado and Wilson, 1994). One reason for this is the system-like—or, in the terminology that we shall make use of, '(Edgeworth) complementary'—way in which HRM practices may connect: complex interactions between many complementary practices are arguably harder for would-be imitators to copy than stand-alone practices (Barney, 1991; Porter and Rivkin, 1997). The complementary nature of many of the elements of (formal and informal) organisational structure has been examined in an emerging and important literature in organisational economics (notably Milgrom and Roberts, 1990, 1995; Aoki and Dore, 1994; Holmström and Roberts, 1998). Insights from this literature have made some impact in the HRM field (Baron and Kreps, 1999).

The connection between firms' internal organisation and their innovativeness has certainly never been neglected in the innovation and evolutionary economics literature: the increasing bureaucratisation of the R&D function was a key theme in Schumpeter's later work. However, it is also fair to say that these literatures are characterised by relatively scant attention being paid to new (complementary) HRM practices and how they influence innovation performance.[1] Something similar may be said of the HRM literature; here too, is a lack of theoretical and empirical treatment of how new HRM practices affect innovation performance.[2] In sum, there is clearly in a number of fields and disciplines an emerging theoretical and empirical understanding of how HRM

[1] The clear exception is constituted by some scholars' interest in Japanese economic organisation and how this connects to innovativeness. Thus, Freeman (1988, p. 335) explicitly notes how in 'Japanese management, engineers and workers grew accustomed to thinking of the entire production process as a system and of thinking in an integrated way about product design and process design', and he makes systematic reference to quality management, horizontal information flows and other features of new HRM practices. One could also construct an argument that already the concern with horizontal information flows in the late 1960s Project SAPPHO demonstrates a long-standing awareness of the relation between HRM practices and innovation performance. However, exceptions may always be found, and we think it is a fair judgement that other determinants of innovation performance, such as appropriability, market structure, control of complementary asserts, etc. have played bigger roles in the literature.

[2] For example, Guest's (1997) programmatic discussion does not mention innovation as a relevant performance variable.

practices and complementarities between these affect productivity and, in turn, financial performance, but that understanding needs to be extended to encompass innovation performance. Accordingly, the purpose of this paper is to add to the theoretical and empirical understanding of how HRM practices and complementarities assist in explaining innovation performance. Thus, we shall argue and demonstrate empirically that new HRM practices, and complementarities between these, affect innovation performance, that is, future competitive advantage.

This paper is one of the first major empirical examinations of the link between innovation performance and complementary new HRM practices. Only a few other papers are available on this topic, including Michie and Sheehan (1999). Thus, for example, while Gjerding (1997) and Mendelson and Pillai (1999) do examine the HRM/performance link, they do not incorporate considerations of complementarity. Lorenz (1998) presents an analysis of complementarities between the use of new HRM practices and so-called new pay policies, but he does not include a measure of performance in the analysis. And Ichniowski *et al.* (1997) discuss the complementarity/performance (productive efficiency) link, but they do not deal with innovation performance. In contrast, we link together complementarity and innovation performance. Furthermore, in our analysis the HRM 'systems' (i.e., particular combinations of HRM practices) *emerge* out of the empirical analysis (namely, from our principal component analysis), while Ichniowski *et al.* (1997) and Michie and Sheehan (1999) *assume* their different systems from the outset. Arguably, Ichniowski *et al.* (1997) are able to define fine-grained controls, since they focus on HRM complementarities found only in steel-finishing lines. However, the drawback is that the conclusions drawn do not cover the entire economy as such. In contrast, we test hypotheses that articulate the HRM/innovation link on a large Danish dataset—the DISKO database—which contains cross-sectional information on the HRM practices and innovation performances of 1,900 privately owned Danish firms in both manufacturing and non-manufacturing industries.

We contribute to several literatures. For instance, our finding that complementarity obtains in HRM practices provides further empirical support for theoretical work on complementarity in organisational economics and elsewhere. Our investigation of the links between complementary HRM practices and innovation performance contributes to the firm strategy literature as well as to the innovation literature. However, we see the present paper as linking up most directly with work in evolutionary economics and innovation studies. Much of this work has had an aggregate focus in which the internal organisation of the firm has been given less attention, and where the main interest has centred on issues such as appropriability, firm size, market structure, complementary assets, etc. as determinants of innovation performance. The findings in this paper may be taken as an indication of the importance of internal factors for the understanding of innovation (while not denying the importance of other factors).

The design of the paper is the following. In Section 2, we begin by reviewing recent work on complementarities in organisational economics. The notion of complementarities allows us to understand better the 'systemic' quality which may characterise not only technologies, but also the organisational elements that constitute the internal organisation of firms. Thus, we argue that complementarities allow us to understand better the clustering of HRM practices in firms. Moreover, the notion of complementarity is helpful for understanding how performance is influenced by such 'systemicness'. Thus, complementarities between HRM practices influence not only the firm's profits but also, as we argue, its innovation performance. In Section 3, we specify an empirical model that allows us to test these ideas on the dataset represented by the DISKO database. We apply an ordered probit model as the relevant means of estimation. Using principal component analysis, we identify two HRM systems which are both conducive to innovation. The first is one in which seven of nine HRM variables matter (almost) equally for the ability to innovate. The second system is dominated by firm-internal and firm-external training. Hence, we conclude that the application of HRM practices does matter for the likelihood of a firm being an innovator. Furthermore, since the two HRM systems are strongly significant in explaining innovation performance, while only two individual practices (out of the total of nine) are found to be strongly significant, we find support for the hypothesis stating the importance of complementarities between certain HRM practices (within each of the two HRM systems) for explaining innovation performance. Section 4 contains a discussion and conclusion.

2. Complementarity, new human resource management practices and innovation performance: theoretical considerations

2.1 The human resource management/innovativeness link: a black box?

Contributions that not only mention but also address theoretically and empirically the link between HRM practices and innovation performance are surprisingly few in number. Although there is a large, somewhat heterogeneous, literature on the management of innovation and technology, much of this literature is largely taken up with strategy issues connected to the exogenous dynamics of technology (e.g., technology life cycles), large-scale organisational issues, and questions relating to appropriability (e.g., Tushman and Moore, 1988). Of course, beginning with Burns and Stalker (1961), the organisational behaviour field has stressed the link between 'organic' organisational structures and innovation performance. A recent stream of pertinent organisational behaviour research has been prompted by March's (1991) distinction between 'exploration' and 'exploitation'.

However, it is not too unfair to say that more precise theoretical identifications of the mechanisms underlying the hypothesised links between HRM practices and innovativeness are virtually non-existent. This is true of both technology management and organisational behaviour literature. To offer further illustrative examples, Baron and Kreps' (1999) recent economics-inspired treatise on HRM does not treat innovativeness as a relevant performance variable. Michie and Sheehan (1999), while empirically finding a link between HRM practices and innovation performance, do not offer a theory of this link. Virtually all the economics literature on the firm level determinants of innovation has dealt with issues such as the famous debates on the relation between firm size and innovation performance (Acs and Audretsch, 1988; Cohen and Klepper, 1996). The organisational factors which may mediate any such relations have largely been black-boxed. Finally, while the emerging evolutionary economics literature on the firm (e.g., Kogut and Zander, 1992; Dosi and Marengo, 1994; Henderson, 1994; Granstrand *et al.*, 1997; Pavitt, 1998; Laamanen and Autio, 2000) has stressed complementarities between diverse technologies and the learning that such complementarities may give rise to, the organisational requirements for coordinating and reaping benefits from these complementarities have not been investigated in any detail.

In sum, therefore, while a number of contributors have noted a link between new HRM practices and innovation performance, and while some contributions have stressed the link between complementary knowledge stocks and innovation performance, no contributions (as far as we know) appear to have put forward theoretical arguments asserting a link between complementary new HRM practices and innovation performance. However, as already indicated, various literatures do contain ideas that are pertinent to the understanding of the link between HRM practices, complementarities between these and innovation performance. We briefly discuss such ideas in the following.

2.2 Complementarities

One of the most important strides forward in the economics of organisation during the last decade is the increasing use that has been made of the notion of Edgeworth complementarities (Milgrom and Roberts, 1990, 1995; Milgrom *et al.*, 1991; Aoki and Dore, 1994; Holmström and Milgrom, 1994; Ichniowski *et al.*, 1997; Holmström and Roberts, 1998; Baron and Kreps, 1999). The pioneers of this application have been Paul Milgrom and John Roberts. As they define it, complementarity between activities obtains if 'doing more of one thing increases the returns to doing (more of) the others' (Milgrom and Roberts, 1995, p. 181). Formally, this will be seen to correspond closely to mixed-partial derivatives of a pay-off function with standard assumptions about the smoothness of this function. However, as Milgrom and Roberts argue, drawing on the mathematical field of lattice theory, the notion of complementarity is not wedded to the conventional differentiable framework.[1] Mathematically, complementarity between a set of variables obtains when a function containing the relevant variables as arguments is supermodular.[2]

There are a number of reasons why scholars in a diverse set of fields, including evolutionary economists, technology studies and organisational behaviour, should take an interest in the notion of complementarities (and the associated formalisms). On the most fundamental level, it provides an understanding of those systemic features of technologies that have traditionally interested such scholars (e.g., national systems of innovation, technology systems).[3] The other side of the coin is that complementarity is an important source of path-dependence: successful change has to involve many, perhaps all, relevant variables of a system and involve them in specific ways.[4] This also helps explain why complementarities are an important source of self-propelled change (cf. Milgrom *et al.*, 1991), that is, 'cumulative change'.[5] Thus, the notion of complementarity is helpful for understanding, for example, technological paradigms and national systems of innovation. At the level of the firm, the notion of complementarity may assist in the understanding of diversification patterns (Granstrand *et al.*, 1997)—for example, it implies that firms will find most profitable new activities (or technologies) in areas that are complementary to newly increased activities (technologies). As we shall further argue, the notion of complementarity is also helpful for understanding the links between organisational variables—specifically, what is here called 'new HRM practices'—and innovation performance.

[1] In terms of the intuition of the notion of complementarity, the notion represents a strong possible conceptualisation of notion such as 'synergy', '(organisational) fit' and 'consistency' (Porter, 1996; Baron and Kreps, 1999).

[2] Given a real-valued function f on a lattice X, f is supermodular and its arguments are complements if for any x and y in X, $f(x)-f(x\wedge y)\leqslant f(x\vee y)-f(y)$ (Milgrom and Roberts, 1995, p. 183). A lattice $(X, \geqslant)$ is a set (X) with a partial order $(\geqslant)$ with the property that for any x and y in X, there is a smallest element $(x\vee y)$ that is larger than x and y and a largest element $(x\wedge y)$ that is smaller than both.

[3] On the method level, it is attractive that complementarities (and the underlying mathematical lattice theory) do not involve the drastic divisibility and concavity assumptions that have often been criticised by evolutionary economists (e.g., Nelson, 1980).

[4] Not surprisingly, the notion has been extensively used in recent research in comparative systems (e.g., Dewatripont and Roland, 1997).

[5] As Milgrom and Roberts (1995, p. 187) point out, a 'movement of a whole system of complementary variables, once begun, tends to continue', thus providing an aspect of the understanding of co-evolution.

2.3 Innovation, complementarities and new human resource management practices

To repeat, 'new HRM practices' is the overall label put on a host of contemporary changes in the organisation of the employment relation, referring to team-based organisation, continuous (often team-based) learning, decentralisation of decision rights and incentives, emphasis on internal knowledge dissemination, etc. While there may be strong financial performance effects, productivity effects and flexibility advantages with such new HRM practices—as documented by Huselid (1995), Ichniowski *et al.* (1997) and Mendelsson and Pillai (1999), respectively—our main emphasis is on the impact on innovation performance, in particular, on product innovation.

New HRM practices can be conducive to innovative activity for a number of reasons. With respect to process innovations/improvements, one notable feature of many new HRM practices is that they increase decentralisation, in the sense that problem-solving rights are delegated to the shopfloor. Accomplished in the right way, this amounts to delegating rights in such a way that they are co-located with relevant knowledge, much of which may be inherently tacit (and thus require decentralisation for its efficient use). In other words, increased delegation may allow better for the discovery and utilisation of local knowledge in the organisation, particularly when there are incentives in place that foster such discovery (Hayek, 1948; Jensen and Meckling, 1992). Indeed, much of the ability of Japanese firms to engage in ongoing, incremental process innovation turns on a successful co-location of problem rights and localised knowledge combined with appropriate pecuniary and non-pecuniary incentives (Aoki and Dore, 1994).

Relatedly, the increased use of teams, which is an important component in the package of new HRM practices, also means that better use can be made of local knowledge, leading to improvements in processes and perhaps also to minor product improvements. However, teams can do something more, since they are often composed of different human resource inputs. This may imply that teams bring together knowledge that hitherto existed separately, potentially resulting in non-trivial process improvements (when teams are on the shopfloor) or 'new combinations' that lead to novel products (Schumpeter, 1912/1934) (when teams are in product development departments). Training of the workforce may be expected to be a force pulling in the direction of a higher rate of process improvements and may possibly also lead to product innovations, depending on the type, amount and quality of relevant training. Generally, increased knowledge diffusion, for example through job rotation, and increased information dissemination, for example through IT, may also be expected to provide a positive contribution to the firm's innovation performance, for rather obvious reasons.

Thus, there are reasons to expect that among the benefits of adopting new HRM practices will be increased innovation performance. Arguably, the adoption of a single such practice may sometimes provide a contribution to innovative performance. For example, the increasingly widespread practice of rewarding shop floor employees for putting forward suggestions for process improvements (e.g., by giving them a share of the cost savings) is likely to increase such incremental innovation activity (Bohnet and Oberholzer-Gee, 2001), more or less regardless of the specific firm in which the reward system is implemented. However, other practices may not be expected to have a significant affect on innovation performance if merely implemented in isolation. At least to the extent that implementing new HRM practices is associated with extra effort or with the disutility of changing to new routines, etc., employees will have to be compensated somehow. Thus, we should expect many new HRM practices to work well (in terms of both profits and innovation performance) only if accompanied by new, typically more incentive-based, remuneration schemes. The evidence appears to support this (Ichniowski *et al.*, 1997).

In general, we should on *a priori* grounds expect new HRM practices to be most conducive to innovation performance when adopted, not in isolation, but as a system of mutually reinforcing practices. The arguments in favour of this are relatively straightforward. For example, the benefits from giving shopfloor employees more problem-solving rights is likely to depend positively on the level of training of such employees. The converse is also likely to hold: employees may invest more in upgrading their skills if they are also given extensive problem-solving rights (i.e., actually to utilise those skills), particularly if they are given the right (intrinsic or extrinsic) motivation. Relatedly, rotation and job-related training may be complements in terms of their impact on innovative activity. All such practices are likely to be complements to various incentive-based remuneration schemes (whether based on individual, team or firm performance), profit-sharing arrangements and promotion schemes (Zenger and Hesterly, 1997).

In sum, while individual new HRM practices may be expected have some positive impact on innovation performance, theory would lead us to expect that, because of complementarities between these practices, systems of HRM practices will be significantly more conducive to innovation than individual practices. In the following, we examine these ideas empirically.

3. Empirical analysis

3.1 The empirical model

Based on the discussion above, the probability of introducing an innovation may be specified as follows:

$$a = f(\beta_1 z, \beta_2 x) \tag{1}$$

Here, a is the probability of introducing an innovation associated with a certain degree of novelty, β_1 and β_2 are parameter vectors, and z is a set of (exogenous) determinants of innovation, related to the application of HRM practices, while x is a set of other variables explaining innovative performance across business firms. The variables included in the vector x are arguably standard variables in the literature aiming to explaining innovation performance (Geroski, 1990; Kleinknecht, 1996). The model may be made operational in the following way:

$$\begin{aligned}\text{Prob}(A_i = 0 \ldots z) = {} & \alpha SIZE_i + \varkappa SECT_i + \delta LINK_i + \phi EXREL_i + \\ & \varphi SUBSID_i + \eta_j HRMP_i^j + \ldots \eta_n HRMP_i^n + \varepsilon_i\end{aligned} \tag{2}$$

where $\text{Prob}(A_i = 0 \ldots z)$ expresses the firms' probability of introducing an innovation associated with a certain degree of novelty on the market. If the firm in question is a non-innovator, the variable takes the value of 0; if the firm has introduced (in the period 1993–95) a product or service new to the firm, the value is 1; if the firm has introduced a product that is new in a Danish context over the period, the value is 2; while the value for this variable is 3 if the firm has introduced a product (or service) that is new to the world.[1] Our sample includes 928 non-innovators, 728 firms that produced products/services which were new only to the firm itself, 125 firms that produced products/services that

[1] Hence, only the final category qualifies for being an innovation in the strict(est) sense of the word.

were new to the national market, while 103 firms introduced products/services that were new to the world. Since our dependent variable is a discrete variable, we apply an ordered probit model as the means of estimation.[1]

As is common in studies aiming at explaining innovative performance (e.g., Geroski, 1990; Michie and Sheehan, 1999), we control for firm size (*SIZE*) and for sectoral affiliation (*SECT*). We include nine sector categories. For what concerns the sectoral classification, we apply the taxonomy developed by Pavitt (1984) and the four corresponding sectors for manufacturing firms. For the service firms in our sample, we construct five additional sectors. Explanations of the sectoral classification that we apply may be found in Appendices 1 and 2 to this paper. As argued by Geroski (1990), such sectoral controls can be interpreted as capturing the differences in technological opportunities which face firms located in different sectors.

Other control variables include whether or not the firm in question has increased its vertical interaction with other firms, whether upstream or downstream (*LINK*). This variable is supposed to pick up the effect of interactions with suppliers and users for innovation performance as stressed by, for example, Lundvall (1988) and von Hippel (1988).

EXREL expresses whether the firm has increased its interaction with knowledge institutions, including technical support institutions, consultancies or with universities. In this context, it may be noted that Brouwer and Kleinknecht (1996) found that firms which had consulted an innovation centre were more likely to innovate than other firms. Although both *LINK* and *EXREL* are concerned with whether firms have increased their external linkages, we interpret these variables more broadly as measuring the strength of the respective linkages. Thus, we argue that respondents who have strong linkages with external partners are very likely to answer that they have *increased* interaction with partners. Finally, we control for whether or not the firm is a subsidiary of a larger firm. The effect of this variable is, however, ambiguous. On the one hand, firms with centralised R&D departments might not wish their subsidiaries to be innovative, as this may hamper economies of scale in R&D. On the other hand, as argued by Harris and Trainor (1995), subsidiary firms might benefit from the larger resource base and experience of the parent firm. Some early empirical studies (e.g., Howells, 1984) found a negative effect of this variable on innovation performance, while more recent studies detected a positive effect (Harris and Trainor, 1995; Love *et al.*, 1996).

The variables $HRMP_i^j \ldots HRMP_i^n$ are our new HRM variables, that is, those variables that are key to the analysis. We include nine discrete variables pertaining to new HRM practices. They express the degree to which firms apply (i) interdisciplinary workgroups, (ii) quality circles, (iii) systems for collection of employee proposals, (iv) planned job rotation, (v) delegation of responsibility (i.e., decision rights), (vi) integration of functions, (vii) performance-related pay, (viii) firm-internal training, and finally (ix) firm-external training. For the first seven variables, the possible values are 0, 1, 2 and 3, which corresponds to the fact that, 0, <25%, 25–50% and >50% respectively of the employees are involved in a given practice. For the last two variables the possible values are 0, 1 and 2, which corresponds to the fact that, 0, <50% and >50% respectively of the employees are involved in a given practice.

[1] Hence, the method is maximum likelihood estimation (MLE), which provides a means of choosing an asymptotically efficient estimator for a set of parameters (for an exposition of the properties of ML estimators, see Greene, 1997, p. 129). Although MLE has been criticised for having less than optimal small sample properties (may be biased, since the MLE of the variance in sampling from a normal distribution is biased downwards), we do not consider this to be a major problem, given the fact that our sample contains about 1,900 firms.

However, as argued earlier, the literature on complementarities suggests that HRM practices are more effective when they are applied in systems relative than when they are applied on a stand-alone basis. Hence, we shall estimate models where HRM practices enter the equation to be estimated in specific configurations or systems:

$$\text{Prob}(A_i = 0 \ldots z) = \alpha SIZE_i + \varkappa SECT_i + \delta LINK_i + \phi EXREL_i + \varphi SUBSID_i + \omega_j HRMS_i^j + \ldots \omega_n HRMS_i^n + \varepsilon_i \quad (3)$$

where the notation is the same as in equation (2). $HRMS_i^j \ldots HRMS_i^n$ denote HRM systems, made up by configurations of our nine HRM practices.[1] Subsequently, we shall estimate both equation (2) and equation (3) separately and compare the significance of the estimations made, when applying the *HRMP*s individually, and when they appear in a HRM system.[2]

Concerning the signs of the parameters for each variable, we expect all signs to be positive, except for the *SECT* variable. In this case, the interpretation has to be made relative to the other sector categories. As for what concerns *SIZE*, we expect larger firms to be more likely to innovate, while we expect the likelihood of innovation at the level of the sector to correspond to what is normally thought of as a high-tech/low-tech typology.

3.2 The data

The main source of data for this paper is the DISKO database. The database is based on a questionnaire which aims at tracing the relationship between technical and organisational innovation in a way that permits analysis of new principles for work organisation and their implications for the use and development of the employee's qualifications in firms in the Danish private business sector. The survey was carried out by the DISKO project at Aalborg University in 1996. The questionnaire was submitted to a national sample of 4,000 firms selected among manufacturing firms with at least 20 full-time employees and non-manufacturing firms with at least 10 full-time employees.[3] Furthermore, all Danish firms with at least 100 employees were included in the sample, that is, a total of 913 firms. The resulting numbers of respondents were 684 manufacturing and 1,216 non-manufacturing firms, corresponding to response rates of, respectively, 52% and 45%.[4] The first descriptive analysis of the survey can be found in Gjerding (1997). The database is held by Statistics Denmark, and the data on the firms in the database can be linked to regular register data (which are also held by Statistics Denmark). For the purposes of the present paper, we have obtained data on the size of the firms in the sample from regular register data.

Table 1 displays descriptive statistics for our explanatory variables.[5] It can be seen from Table 1 that the most widely dispersed HRM practice is 'delegation of responsibility', since only 15·9% of the firms do not apply this practice at all. Of the firms, 39.1% use this practice, while involving more than 50% of their employees. The least diffused practice is

[1] The way in which the HRM practices are transformed into 'systems' will be explained in the section below.

[2] If the effect of individual practices as well as the systems of practices were estimated in the same model, this would result in perfect collinearity.

[3] In the stratification of the sample, firms with less than 10 employees were excluded from the analysis. However, in our analysis, we have a size category containing firms smaller than 10 employees. The reason for this is that when the sample was stratified, size was measured at a given point in time. However, in this paper, we measure size as the number of full-time employees over a full year.

[4] The full questionnaire is available in English, as an appendix to Lund and Gjerding (1996, Appendix 1).

[5] Of the total of 1,900 responding firms, data are not available for size or for sectoral affiliation for 16 of those firms. Hence, we conduct our analysis using information on 1,884 firms.

Table 1. *Descriptive statistics for a set of DISKO variables (n = 1,884)*

% of firms using a *HRMP*				
Variable	% of employees involved for each firm			
	None	<25%	25–50%	>50%
Interdisciplinary workgroups	51·0	27·0	12·9	9·1
Quality circles	62·5	18·7	9·0	9·8
Systems for collection of employee proposals	56·1	18·0	7·2	18·7
Planned job rotation	64·3	22·0	7·1	6·6
Delegation of responsibility	15·9	22·0	23·0	39·1
Integration of functions	43·7	28·9	14·3	13·1
Performance-related pay	61·0	16·6	6·9	15·5
% of firms using a *HRMP*				
	% of employees involved for each firm			
	None	<50%	>50%	
Firm-internal training	48·2	23·0	28·8	
Firm-external training	30·7	38·7	30·6	
	% of total sample			
Applies at least two *HRMP*s (*HRMPONE*)	94·5			
Applies at least three *HRMP*s (*HRMPTHREE*)	66·7			
Scale-intensive	13·5			
Supplier-dominated	11·9			
Science-based	3·6			
Specialised suppliers	7·3			
Crafts	14·5			
Wholesale trade	17·7			
Specialised traditional services	19·6			
Scale-intensive services	5·0			
ICT intensive services	6·9			
1–10 employees	11·7			
11–50 employees	52·0			
51–100 employees	10·9			
100+ employees	25·4			

'planned job rotation', where 64·3% of the firms do not use this practice at all. Of the firms, 94·5% apply at least one of the *HRMP*s, while 66·7% apply at least three such practices. For what concerns the distribution on sectors and across size categories, it may be seen that none of the groups is either extremely large or extremely small. Since the analysis contains many different variables, each reflecting different aspects of *HRMP*s, we use principal component analysis in order to reduce the number of variables in the regression analysis to be carried out subsequently. The principal component technique—which is a form of factor analysis—estimates linear combinations of the underlying variables, in this case the indices of various work practices, that 'explain' the highest possible fraction of the remaining variance in the dataset. Thus, the first principal component is estimated to explain the highest possible fraction of the total variance, the second principal component the highest possible fraction of the variance which is not explained by the first principal component, etc. By maximising the 'explained residual variance' in each round, the first m ($<n$) principal component will explain a relatively large proportion of the total

variance. Since our variables are discrete, we have followed the normal procedure by transforming (or 'smoothing') the variables using the method of alternating least squares, before conducting the principal component analysis.

An economic interpretation of the sets of factor loadings[1] ('factors') from the factor analysis is that the 'typical' pattern is one in which some of the above-mentioned work practices play a major role. Accordingly, we interpret each of the factors as 'HRM systems'. The sets of factor loadings for each factor are reported in Table 2. It can be seen from Table 2 that we include two factors in the analysis. The reason for retaining two factors is that *Factor 2* is the last factor (of the potential nine factors), where the eigenvalue exceeds one. In other words, *Factor 2* explains more of the total variance than each of the nine individual *HRMP* variables does, whereas *Factor 3* explains less than any one of the nine original variables. The factors have been rotated using orthogonal Varimax rotation. This operation 'amplifies' the initial (non-rotated) factors, so that the factors become more distinct.[2]

Factor 1 in Table 2 is the first of our HRM systems. In this case, the factor loadings are all positive and have all approximately the same size (factor loadings of about 0·5–0·7), except for firm-internal and firm-external training, cases in which the values of the factor loadings are rather low. Nevertheless, *Factor 1* expresses a HRM system in which seven of our nine *HRMP*s are equally important. Note that each individual firm which scores highly on *Factor 1* is not necessarily applying all seven *HRMP*s simultaneously.[3] However, it does imply that a firm which scores highly on *Factor 1* applies several of the seven *HRMP*s. Hence, this system (*Factor 1*) is one in which all seven practices are applied in just about equal proportions. In the same manner, *Factor 2* is dominated by firm-internal and firm-external training (factor loadings of 0·9).

3.3 Estimation

The estimations of our models can be found in Table 3. First, it may be noted that the null hypothesis that the slopes of the explanatory variables are zero is strongly rejected by the likelihood ratio test for all our three specifications. Furthermore, it may be seen from the

Table 2. *Factor loadings for nine organisational variables (Varimax rotation, n = 1,884)*

Variable	Factor 1	Factor 2
HRMP1: Interdisciplinary workgroups	0·71	0·14
HRMP2: Quality circles	0·66	0·15
HRMP3: Systems for collection of employee proposals	0·65	0·04
HRMP4: Planned job rotation	0·62	0·08
HRMP5: Delegation of responsibility	0·57	0·03
HRMP6: Integration of functions	0·65	–0·05
HRMP7: Performance-related pay	0·55	0·05
HRMP8: Firm-internal training	0·14	0·90
HRMP9: Firm-external training	0·02	0·92
Cumulative %	0·33	0·50

[1] The factor loadings are the parameters relating the original variables to the principal components.

[2] We have experimented with oblique rotation methods as well, but the choice of oblique rather than orthogonal methods does not change the results in any important way.

[3] Admittedly, it is a weakness of the principal component methodology that the size of each factor loading chosen, for one to conclude that an underlying variable is 'important', is somewhat arbitrary.

Table 3. *Ordered probit regressions, explaining innovative performance across 1,884 Danish firms*

Variable	Model (i) Estimate	Model (i) *p*-value	Model (ii) Estimate	Model (ii) *p*-value	Model (iii) Estimate	Model (iii) *p*-value
Sector controls						
Scale-intensive	–0·242	0·061	–0·182	0·172	–0·247	0·063
Supplier-dominated	–0·275	0·037	–0·190	0·162	–0·301	0·026
Science-based	–0·143	0·418	–0·111	0·536	–0·132	0·469
Specialised suppliers	0·082	0·567	0·181	0·215	0·079	0·590
Crafts	–0·948	0·000	–0·877	0·000	–0·964	0·000
Wholesale trade	–0·203	0·098	–0·176	0·161	–0·210	0·098
Specialised traditional services	–0·722	0·000	–0·654	0·000	–0·725	0·000
Scale-intensive services	–0·694	0·000	–0·631	0·000	–0·748	0·000
ICT intensive services	Benchmark		Benchmark		Benchmark	
SIZE	0·016	0·043	0·015	0·064	0·018	0·029
LINK	0·614	0·000	0·598	0·000	0·595	0·000
EXREL	0·267	0·000	0·247	0·000	0·270	0·000
SUBSID	0·127	0·042	0·098	0·123	0·130	0·043
Factor 1	0·192	0·000				
Factor 2	0·063	0·027				
HRMP1			0·025	0·466		
HRMP2			0·010	0·744		
HRMP3			0·042	0·114		
HRMP4			0·041	0·246		
HRMP5			0·055	0·066		
HRMP6			0·067	0·024		
HRMP7			0·051	0·059		
HRMP8			0·154	0·000		
HRMP9			–0·004	0·924		
HRMPONE					0·423	0·027
HRMPTHREE					0·378	0·000
Log likelihood		–1757·5		–1742·0		–1755·8
Restricted log likelihood		–1987·8		–1987·8		–1987·8
Log likelihood test		460·4		491·6		464·0

table that large firms are more likely to innovate than small firms (e.g., in model i), although the effect is not particularly strong. Given that our dependent variable is not a measure of the frequency of innovation, this finding is not surprising, but should be controlled for.[1]

It can be seen from Table 3 that the likelihood of firms being innovators, given their sectoral affiliation, can be ranked as follows: (1) specialised suppliers, (2) ICT (Information and Communication Technology) intensive services, (3) science-based, (4) wholesale trade, (5) scale-intensive, (6) supplier-dominated, (7) scale-intensive services, (8) specialised

[1] The marginal effects from the probit analysis (corresponding to the coefficients shown in Table 3) are reported in the Appendix 3, Tables A1–A3. They show that the probability of introducing an innovation increases with firm size, since the marginal effect for the SIZE variable is negative only in the case of no innovation ($A=0$), while the marginal effect is positive in the case of innovation at all levels of novelty ($A=1$, 2, 3). Indeed, this is the interpretation which can be put on all of the significant coefficients (including the parameters for the HRM variables), since the marginal effects are negative only in the case of no innovation ($A=0$) for all significant coefficients. However, it can also be noted that the marginal effects are larger for $A=1$ (than for $A=2$ and $A=3$), that is, the explanatory variables have the strongest effect on introducing a product 'new to the firm'.

traditional services, and (9) crafts. Such a ranking may be said to be in agreement with what one would expect on more intuitive grounds, since it is so clearly related to whether sectors are 'high-tech' or 'low-tech' (OECD, 1996).

The results also confirm that the external linkages of firms are important to innovation, since both the parameters for vertical linkages (*LINK*) and for other knowledge linkages (*EXREL*) are significantly different from zero. It may be noted, however, that upstream or upstream linkages are particularly important, given the high parameter for this variable. The latter finding is in line with the predictions of Lundvall (1988) and von Hippel (1988) and with the empirical findings of Rothwell *et al.* (1974) and Malerba (1992). The variable for being a subsidiary has a positive sign, and is significant in models (i) and (iii).

By inserting the two retained factors from the principal component analysis described above into the regression, we find that both HRM systems are conducive to innovation.[1] The first is *Factor 1* from Table 2, in which seven of our nine HRM variables (namely, 'interdisciplinary workgroups', 'quality circles', 'systems for collection of employee proposals', 'planned job rotation', 'delegation of responsibility', 'integration of functions', and 'performance-related pay') matter (almost) equally for a firm's ability to innovate. The second system, which is found to be conducive to innovation (*Factor 2* from Table 2) is dominated by 'firm-internal' and 'firm-external training'. Hence, based on the principal component regression we can—as a first step—conclude that *HRMP*s matter for the ability of firms to innovate. It should be noted that, while the significant estimates for the *HRMP* variables are consistent with the view that the application of 'new' HRM practices is conducive to innovation performance, it is equally clear that—given the cross-sectional nature of the present data—strong inferences about causality cannot be made. In fact, Capelli and Neumark (2001) use panel data and find only weak evidence for the effect of 'high-performance' work practices on labour productivity.

Concerning our hypothesis on complementarity of *HRMP*, it may be seen from Table 3 (model ii) that only four of the *HRMP*s are individually significant, and moreover, that only 'integration of functions' (*HRMP6*) and 'firm-internal training' (*HRMP8*) are significant at the 5% level. However, when seven *HRMP*s (all but firm-external and firm-internal training) of the *HRMP*s are combined into a single variable (a 'system'), this 'synthetic' variable (*Factor 1*) is strongly significant. Seven out of the nine *HRMP*s appear to be complementary, since they jointly (as expressed by *Factor 1*) give rise to better innovation performance. This pattern applies to one group of firms, while for another group of firms, complementarity between firm-internal training and firm-external training (as expressed by *Factor 2*) appear to be the important factor with respect to explaining firms' ability to innovate. *Factor 2* is significant at the 5% level. We take the two positive and significant results for the system variables as evidence of the existence of Edgeworth complementarities between the *HRMP*s in our analysis.

However, it is not clear why the *HRMP*s cluster in exactly these ways, and we can only speculate on the reasons for the above pattern, since the dataset does not allow us to resolve the issue. In this context, one can argue that it is surprising that as many as seven of the total of nine practices turn out to be complementary (as expressed by *Factor 1*). However, it should be noted that we have not selected the work practices examined at random. Rather, we have chosen some of the practices already identified in the literature as being relevant candidates for obtaining complementarities (with other practices).

[1] Other examples of principal component regression include Arvanitis and Hollenstein (1996), in which the effects on innovation performance of various sources of innovation are examined. In the field of international economics, Dalum *et al.* (1999) analysed the effect of international patterns of specialisation on economic growth, while applying the methodology.

The majority of the variables underlying *Factor 1* are intuitively complementary. For instance—and as argued in the theoretical section of this paper—'performance-related pay' appears to go hand in hand with team-based practices such as 'interdisciplinary workgroups' and 'quality circles'. Moreover, it appears that the team practices can successfully be used jointly with 'delegation of responsibility', since the use of such team-based practices does not make much sense without at the same time allocating the appropriate decision rights down to team level. However, some of the work practices underlying *Factor 1* could be seen to be substitutes, rather than complements. For instance, 'planned job rotation' and 'integration of functions' could, at a first glance, be seen to be substitutes. However, on closer inspection—and as pointed out by Aoki (1990) in the context of product development—the use of team-work involving job rotation increases the interaction between the different key actors in various successive stages (basic conceptualisation, successive phases of detailed design, prototype fabrication, testing, redesign, mass production and marketing) of product development. Since processes of product development are characterised by various feedback loops between the 'phases' (Kline and Rosenberg, 1986), job-rotation among different engineering offices, as well as between engineering jobs and supervisory jobs at the factory, facilitates the knowledge-sharing needed for horizontal coordination among the different phases of development.

With respect to the two training variables, captured by *Factor 2*, it is surprising that these practices were found not to be complementary to other HRM practices. However, note that while these may conceivably be expected on *a priori* grounds to be complementary to other HRM practices (e.g., 'performance-related pay' or 'delegation of responsibility'), captured by *Factor 1*, one may also point out that these practices are arguably the most traditional of the nine *HRMP*s that we consider; for example, even very traditional, hierarchical industrial firms are likely to make use of some internal training. Thus, one may expect firms that otherwise will not apply *HRMP*s to make use of some training. Moreover, there may be a significant size bias here, since small firms that (because of their smallness) need not make use of *HRMP*s to any great degree may still make considerable use of external training. Taken together, these effects may help explain the pattern in the application of *HRMP*s.

Another way of gauging *HRMP* complementarities is to look at whether it is sufficient to apply at least one *HRMP*, rather than it being necessary to apply several practices together. In Table 3, model (iii), we test the hypothesis of the positive effect of having at least one *HRMP*, against the alternative hypothesis stating the positive effect of applying three or more *HRMP*s at the same time. Both variables, *HRMPONE* and *HRMPTHREE*, are binary variables, taking into account only whether or not a certain practice is used, and not the degree to which the practice is used within each firm (in contrast to the previous analysis). Although having at least one practice (*HRMPONE*) is positive and significant when entered in the regression alone (not shown for reasons of space), *HRMPONE* is significant only at the 5% level, when taken together with the variable expressing whether or not each firm apply three or more HRM practices (*HRMPTHREE*). In contrast, *HRMPTHREE* is highly significant ($p<0{\cdot}0001$). We take this as further evidence of the importance of complementarities between new HRM practices with respect to determining innovation performance.[1]

[1] It can be noted that we have tested our models not only by using an ordered probit model, as documented in the Table 3, but also by making standard binary probit estimations (collapsing our discrete dependent variable into a binary variable, which takes the value of zero if the firm does not innovate and takes the value of one if the firm innovates). This change of estimation method does not change our results in any important way.

The final part of our analysis is devoted to the assessment of whether sectoral regularities in the application of the two (successful) HRM systems can be detected. Despite the fact that the correlation coefficients are not very high in Table 4, we find that, of our total of nine sectors, the four manufacturing sectors correlate positively with the first system. Firms belonging to the wholesale trade and to the ICT intensive service sectors tend to be associated with the second system (firms in the scale-intensive sector tend to be associated with the second system as well, although the association is rather weak). Hence, it seems fair to conclude that, as a general matter, sectoral regularities in the effect of *HRMP* complementarities on innovation performance exist.

4. Discussion and conclusion

We began by noting a number of stylised facts that relate to the ongoing changes in the nature of the employment relation—often conceptualised by the term, 'new HRM practices'–to the apparently systemic nature of these practices, and to their adoption by innovative firms. We argued that the notion of complementarities (and the associated theorising and formalisms) is helpful for allowing us to construct explanations of these stylised facts. In particular, we argued that, while the adoption of individual HRM practices may be expected to influence innovation performance positively, the adoption of a package of complementary HRM practices could be expected to affect innovation performance much more strongly. However, we have not offered a fine-tuned theory about why this should be so. In general, there is very clearly a theoretical deficit in this area. Future work will be devoted to theorising the links between complementary HRM practices and innovation performance more comprehensively. However, the main emphasis of the present paper is empirical.

In our empirical analysis of these overall ideas and hypotheses, we began by finding that strong linkages to users or suppliers are conducive to innovation (while controlling for size and sectoral affiliation). Moreover, strong linkages to knowledge institutions, including technical support institutions, consultancies or universities, were similarly found to be conducive to innovation. With respect to the application of new HRM practices, we applied principal component analysis in order to compress the information from the survey and in order to identify possible patterns of HRM practices. Hence, in our analysis, the HRM 'systems' emerged out of the principal component analysis, while previous contributions in the field have assumed different systems from the outset. Using the principal component tool, we identified two HRM systems which are conducive to inno-

Table 4. *Correlations amongst HRM systems and the firm's sectoral affiliation*

	Factor 1	*p*-value	*Factor 2*	*p*-value
Scale-intensive	0·16	0·000	0·05	0·031
Supplier-dominated	0·08	0·001	–0·09	0·000
Science-based	0·12	0·000	0·02	0·490
Specialised suppliers	0·15	0·000	–0·07	0·002
Crafts	–0·20	0·000	–0·11	0·000
Wholesale trade	0·00	0·936	0·08	0·001
Specialised services	–0·17	0·000	0·06	0·006
Scale-intensive services	–0·05	0·041	–0·09	0·000
ICT intensive services	0·03	0·178	0·12	0·000

vation. The first is one in which seven of our nine HRM variables matter (almost) equally for the ability to innovate. The second system, which was found to be conducive to innovation, is dominated by firm-internal training in addition to firm-external training. Hence, we conclude that the application of HRM practices does matter for the likelihood of a firm being an innovator. Furthermore, since the two HRM systems were strongly significant in explaining innovation performance, while only two individual practices (out of nine) were found to be strongly significant, we found support for the hypothesis of the importance of Edgeworth complementarities between certain HRM practices within each of the two HRM systems.

The final part of our analysis was devoted to assessing whether sectoral regularities in the application of the two (successful) HRM systems could be detected. Of our total of nine sectors, we found that the four manufacturing sectors correlate with the first system. Firms belonging to the wholesale trade sector and to the ICT intensive service sector tend to be associated with the second system. Theoretical analysis has focused almost exclusively on identifying organisational practices and complementarities between such practices, irrespective of the type of activity in question (e.g., Milgrom and Roberts, 1995). Hence, in order to inform future theoretical research in the field, further empirical research should be devoted to the more detailed unfolding of sectoral regularities in the effect of HRM practice complementarities on innovation performance.[1]

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[1] For a preliminary empirical analysis in this direction, see Laursen (2002).

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Appendix 1: the sectoral classification applied in the present paper

Pavitt (1984) identifies differences in the importance of different sources of innovation according to which broad sector the individual firm belongs to. The Pavitt taxonomy—which is based on grouping firms according to their principal activity—emerged out of a statistical analysis of more than 2000 post-war innovations in Britain. The underlying explanatory variables are the sources of technology; the nature of users' needs; and firms' means of appropriation. Based on this, four overall types of firms were identified, namely, supplier-dominated firms, scale-intensive firms, specialised suppliers and science-based firms. *Supplier-dominated* firms are typically small. Most technology comes from suppliers of equipment and material. *Scale-intensive* firms are found in bulk materials and assembly. Their internal sources of technology are production engineering and R&D departments. External sources of technology include mainly interactive learning with specialised suppliers, but also inputs from science-based firms are of some importance. *Specialised suppliers* are small firms, producers of production equipment and control instrumentation. Their internal sources of technology are design and development. External sources are users (science-based and scale-intensive firms). *Science-based firms* are found in the chemical and electronic sectors. Their main internal sources of technology are internal R&D and production engineering. Important external sources of technology include universities, but also specialised suppliers.

Because the Pavitt taxonomy was created with mainly the manufacturing sector in mind (although our *crafts* sector [see below] could be included in the *supplier-dominated* sector, if one were to follow the original Pavitt taxonomy), and since we are conducting an analysis of firms in both manufacturing as well as in services, we have added five additional service sectors. *ICT (Information and Communication Technology) intensive services* are firms providing business services and financial services. *Wholesale trade* consists of firms selling bulk materials or machines. *Scale-intensive services* consists of typically large firms in the transport industries, cleaning service as well as of supermarkets and warehouses. *Specialised services* is made up of smaller firms including miscellaneous shops, hotels and restaurants, taxi companies etc. *Crafts* consists of firms in construction industries, as well as of automobile repair shops.

For a detailed assignment of all industries into our nine sectors, see Appendix 2.

Appendix 2: the assignment of industries into nine sectoral categories

No.	Industry	Sector	No.	Industry	Sector
1	Production etc. of meat and meat products	SCAI	43	Sale of motor vehicles, motorcycles etc.	SSER
2	Manufacture of dairy products	SCAI	44	Maintenance and repair of motor vehicles	CRAF
3	Manufacture of other food	SCAI	45	Service stations products	SSER
4	Manufacture of beverages	SCAI	46	Ws. of agricul. raw materials, live animals	WTRA
5	Manufacture of tobacco products	SCAI	47	Ws. of food, beverages and tobacco	WTRA
6	Manufacture of textiles and textile products	SDOM	48	Ws. of household goods	WTRA
7	Mfr. of wearing apparel; dressing etc. of fur	SDOM	49	Ws. of wood and construction materials	WTRA
8	Mfr. of leather and leather products	SDOM	50	Ws. of other raw mat. and semimanufactures	WTRA
9	Mfr. of wood and wood products	SDOM	51	Ws. of machinery, equipment and supplies	WTRA
10	Mfr. of pulp, paper and paper products	SDOM	52	Commission trade and other wholesale trade	WTRA
11	Publishing of newspapers	SDOM	53	Re. sale of food in non-specialised stores	SCIS
12	Publishing activities, excl. newspapers	SDOM	54	Re. sale of food in specialised stores	SSER
13	Printing activities etc.	SDOM	55	Department stores	SCIS
14	Mfr. of refined petroleum products etc.	SCAI	56	Retail sale of phar. goods, cosmetic art. etc.	SSER
15	Mfr. of chemical raw materials	SCIB	57	Re. sale of clothing, footwear etc.	SSER
16	Mfr. of paints, soap, cosmetics, etc.	SCAI	58	Re. sale of furniture, household appliances	SSER

No. Industry	Sector	No. Industry	Sector
17 Mfr. of pharmaceuticals etc.	SCIB	59 Re. sale in other specialised stores	SSER
18 Mfr. of plastics and synthetic rubber	SCAI	60 Repair of personal and household goods	SSER
19 Mfr. of glass and ceramic goods etc.	SDOM	61 Hotels etc.	SSER
20 Mfr. of cement, bricks, concrete ind. etc.	SCAI	62 Restaurants etc.	SSER
21 Mfr. of basic metals	SCAI	63 Transport via railways and buses	SCIS
22 Mfr. construction materials of metal etc.	SCAI	64 Taxi operation and coach services	SSER
23 Mfr. of hand tools, metal packaging etc.	SDOM	65 Freight transport by road and via pipelines	SSER
24 Mfr. of marine engines, compressors etc.	SPEC	66 Water transport	SCIS
25 Mfr. of other general purpose machinery	SPEC	67 Air transport	SCIS
26 Mfr. of agricultural and forestry machinery	SPEC	68 Cargo handling, harbours etc.; travel agencies	SCIS
27 Mfr. of machinery for industries etc.	SPEC	69 Monetary intermediation	ITIS
28 Mfr. of domestic appliances n.e.c.	SCAI	70 Other financial intermediation	ITIS
29 Mfr. of office machinery and computers	SCIB	71 Insurance and pension funding	ITIS
30 Mfr. of radio and communication equipment etc.	SCIB	72 Activities auxiliary to financial intermediates	ITIS
31 Mfr. of medical and optical instruments etc.	SPEC	73 Letting of own property	SSER
32 Building and repairing of ships and boats	SCAI	74 Real estate agents etc.	SSER
33 Mfr. of transport equipment excl. ships, etc.	SCAI	75 Renting of machinery and equipment etc.	SSER
34 Mfr. of furniture	SDOM	76 Computer and related activity	ITIS
35 Mfr. of toys, gold and silver articles etc.	SDOM	77 Research and development	ITIS
36 General contractors	CRAF	78 Legal activities	ITIS
37 Bricklaying	CRAF	79 Accounting, book-keeping and auditing activities	ITIS
38 Install. of electrical wiring and fittings	CRAF	80 Consulting engineers, architects etc.	ITIS
39 Plumbing	CRAF	81 Advertising	ITIS
40 Joinery installation	CRAF	82 Building-cleaning activities	SCIS
41 Painting and glazing	CRAF	83 Other business services	ITIS
42 Other construction works	CRAF		

SCAI = Scale-intensive firms; SDOM = Supplier-dominated firms; SCIB = Science-based firms; SPEC = Specialised suppliers; CRAF = Crafts; WTRA = Whole sale trade; SSER = Specialised services; SCIS = Scale-intensive services; ITIS = ICT intensive services.

Appendix 3: marginal effects from the ordered probit analysis

Table A1. *Marginal effects from Table 3, model (i)*

	$A = 0$	$A = 1$	$A = 2$	$A = 3$
SIZE	–0·0059	0·0037	0·0012	0·0010
LINK	–0·2387	0·1493	0·0483	0·0412
EXREL	–0·0986	0·0617	0·0199	0·0170
SUBSID	–0·0390	0·0244	0·0079	0·0067
HRMP1: Interdisciplinary workgroups	–0·0099	0·0062	0·0020	0·0017
HRMP2: Quality circles	–0·0042	0·0026	0·0008	0·0007
HRMP3: Systems for collection of employee proposals	–0·0167	0·0104	0·0034	0·0029
HRMP4: Planned job rotation	–0·0162	0·0101	0·0033	0·0028
HRMP5: Delegation of responsibility	–0·0219	0·0137	0·0044	0·0038
HRMP6: Integration of functions	–0·0268	0·0168	0·0054	0·0046
HRMP7: Performance-related pay	–0·0202	0·0126	0·0041	0·0035
HRMP8: Firm-internal training	–0·0615	0·0385	0·0124	0·0106
HRMP9: Firm-external training	0·0015	–0·0010	–0·0003	–0·0003

Table A2. *Marginal effects from Table 3, model (ii)*

	$A = 0$	$A = 1$	$A = 2$	$A = 3$
SIZE	–0·0063	0·0039	0·0013	0·0011
LINK	–0·2451	0·1510	0·0503	0·0438
EXREL	–0·1066	0·0657	0·0219	0·0191
SUBSID	–0·0507	0·0312	0·0104	0·0091
Factor 1	–0·0766	0·0472	0·0157	0·0137
Factor 2	–0·0253	0·0156	0·0052	0·0045

Table A3. *Marginal effects from Table 3, model (iii)*

	$A = 0$	$A = 1$	$A = 2$	$A = 3$
SIZE	–0·0070	0·0043	0·0014	0·0012
LINK	–0·2372	0·1469	0·0482	0·0421
EXREL	–0·1076	0·0666	0·0219	0·0191
SUBSID	–0·0520	0·0322	0·0106	0·0092
NWPONE	–0·1689	0·1046	0·0343	0·0300
NWPTHREE	–0·1509	0·0934	0·0307	0·0268