Forms of Knowledge, Modes of Innovation and Innovation Systems

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Abstract: Inspired by the concepts tacit and codified knowledge introduced by Polanyi, this paper makes a distinction between two modes of innovation. On the one hand there are innovation strategies (Science, Technology, and Innovation, STI-mode) that give main emphasis to promoting R&D and creating access to explicit codified knowledge. On the other hand there are innovation strategies (Doing, Using, and Interacting, DUI-mode) mainly based on learning by doing, using and interacting. We show that firms using mixed strategies that combine a strong version of the STI-mode with a strong version of the DUI-mode excel in product innovation. The distinctions made and the results obtained have important implications for innovation policy and for the analysis of innovation systems. They help to avoid biased approaches exaggerating the role of science-based innovation while also indicating limits for experience-based innovation strategies.

Key words: Knowledge management, interactive learning, learning economy, innovation systems**.**

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1. Introduction

This paper is about the tension between two ideal type modes of learning and innovation. One mode is based on the production and use of codified scientific and technical knowledge, the Science, Technology and Innovation (STI) mode, and one is an experienced-based mode of learning based on Doing, Using and Interacting (DUI-mode). At the level of the firm, this tension may be seen in the need to reconcile knowledge management strategies prescribing the use of ICT as tools for codifying and sharing knowledge with strategies emphasizing the role played by informal communication and communities of practice in mobilizing tacit knowledge for problem-solving and learning.

At the level of the whole economy, the tension between the STI and DUI modes corresponds to a need to reconcile and combine approaches to national innovation systems focusing on the role of formal processes of R&D in order to produce explicit and codified knowledge with those focusing on the learning from informal interaction within and between organisations resulting in competence-building often with tacit elements.

There is, of course, an important body of empirical and historical work showing that both modes of learning and innovation play a role in most sectors, the role being different depending on context as well as strategy (von Hippel, 1976; Rothwell, 1977; Rosenberg, 1982; Pavitt, 1984). Recent models of innovation emphasize that innovation is an interactive process in which firms interact both with customers and suppliers and with knowledge institutions (Freeman, 1986; Kline and Rosenberg, 1986; Lundvall, 1988; Vinding, 2002).

Despite the broad acceptance of this literature, there remains a bias among scholars and policy makers to consider innovation processes largely as aspects connected to formal processes of R&D, especially in the science-based industries. At the policy level this can be seen in the emphasis on benchmarking variables related to STI and in their focus on such instruments as tax subsidies to R&D, the training of scientists in high-tech fields such as ICT, bio- and nano-technology and strengthening the linkages between firms and universities in these specific fields. At the level of scholarly research, there is a tendency to expect that the increasing reliance on science and technology in the 'knowledge-based economy' will enhance the role played by formal processes of R&D requiring personnel with formal S&T qualifications. And the vast majority of quantitative survey-based studies of innovation simply have little to say about the relation of DUI-mode learning to innovative performance.[1]

In what follows we argue that by focusing the analysis on the frameworks and structures that promote learning within and across organisations it is both possible to develop meaningful measures of DUI-mode learning and to demonstrate that firms can promote such learning through particular practices and policies. Utilizing data from the Danish DISKO Survey (Lundvall, 2002 summarizes the results from DISKO - a project on the Danish innovation system in comparative perspective), we present what we believe to be the first quantitative survey-based analysis of the way the two modes of learning contribute to innovative performance. Our empirical results not only show that the two modes of learning are practised with different intensities in different firms but also that firms combining them are more innovative.

In sections 2 and 3 we develop definitions of the two modes of learning and show how they are connected to different types of knowledge. Section 4 explores the relations between the two modes, pointing to factors that encourage firms to adopt mixed strategies combining the two modes rather than relying predominately on one mode or the other. Section 5 develops the empirical indicators of the modes and explores econometrically the relation between their use and innovative performance for a representative sample of Danish firms. Section 6 relates the two modes of learning to innovation system research and points to important policy implications.

[1] This bias is similar to the 'S&T perspective' that gives too much weight to S&T-indicators, especially R&D spending, for understanding technological innovation as discussed by Laestadius (1998). On the basis of in depth case studies from the pulp and paper sector in Sweden he argues that this bias has implied a relative neglect of innovation in for example mechanical technologies and other low and medium tech areas. Furthermore, development costs in these areas are often underreported and/or accounted as other types of costs. It turns out that R&D data only have a weak relation to what is actually going on in the sector. We share Laestadius view that such a bias exists in both theory and policy-making. Our methodology differs from Laestadius', however, in that we use quantitative survey data. Our focus is also a bit different since we concentrate on types of learning rather than on technologies.

2. What is knowledge?

Explicit versus implicit knowledge

The two learning modes presented and analysed in this paper relate to different types of knowledge. Thinking about knowledge seems to have resulted in a number of two-sided distinctions (dichotomies). We have already mentioned the distinction between tacit and codified knowledge (or rather between tacit and codified elements of knowledge) on which there is now a vast literature and a lively debate (Cowan, David and Foray, 2001; Johnson, Lorenz and Lundvall, 2002). One way to make knowledge explicit is to write it down. Knowledge that can be written down may be passed on to others and be absorbed by those who can read and understand the specific language. But absorbing such knowledge is seldom automatic – the idea of effortless 'knowledge transfer' is normally misleading and a 'prepared mind' helps a lot when it comes to absorbing codified knowledge. Furthermore, often knowledge can be partially but not totally written down as for example in the typical 'book of instruction'. In order to understand messages about the world you need to have some prior knowledge about it. In order to implement 'recipes' about how to manage and change the world you will often need to have prior skills and competences. Scientific texts give meaning only to other scientists and manuals may prove useful only to highly skilled workers. This implies that codified knowledge that stands alone is not economically useful.

Local versus global knowledge

Codification and efforts to make explicit what is implicit may be seen as one important way to enhance the capacity to share knowledge in society. But to codify knowledge does not necessarily make it more accessible to others. Using a 'secret code' is a way to establish the opposite effect. In the seminal article from 1974, Kenneth Arrow uses the concept 'codes of information' with reference to more efficient means of communication inside an organization to the exclusion of outsiders. Lundvall (1988) drew on Arrow's insight in arguing that establishing common codes provides a basis for efficient local communication between users and producers in the context of product innovation.

Neither is codification the only way to generalize knowledge. Education and training systems generalize knowledge and 'embody' knowledge in people. Machinery producers may embody general knowledge in technical systems and knowledge intensive business service firms may deliver disembodied general knowledge to customers as standard solutions. The mobility of workers is another important mechanism for spreading experience-based knowledge.[2] From the point of view of the whole economy, the transformation of local knowledge into global knowledge is of great interest.

Actually, in economic practice it is seldom a question of working with knowledge that is either tacit or codified. The zone in between and the complementarities between the tacit and codified elements of knowledge are often what matters most (Nonaka and Takeuchi, 1995). The same is true for the distinction between local and global knowledge. When we make the distinction between the two modes of innovation and relate this to the different forms of knowledge this should be kept in mind. What is referred to are two 'ideal types' that appear in a much more mixed form in real life.

From know-what to know-who

The dichotomies mentioned above have played an important role in the discussion of the concept of knowledge in business and economics and they have contributed to better understanding of its intricacy. They in turn can be linked to a somewhat more elaborate set of distinctions developed by Lundvall and Johnson (1994) that are useful for understanding the different channels and mechanisms through which learning different types of knowledge takes place.

- Know-what
- Know-why
- Know-how
- Know-who

Learning the four types of knowledge tends to take place in different ways and through different channels. While important aspects of know-what and know-why may be obtained through reading books, attending lectures and accessing data bases, the two

[2] For example, in the early industrialization of Sweden the use of synthetic dyestuff in textiles was learnt through immigration of skilled labour from Germany. The electrification of Sweden was based upon headhunting of Scandinavians that had migrated to the US and worked in that country's electric industry (Fridlund, 1999).

other categories are more rooted in practical experience. Written manuals may be helpful but in order to use them some prior basic skills in the field of application are usually needed. The STI-mode gives high priority to the production of ‘know-why’ while the DUI-mode typically will produce ‘know-how’ and ‘know-who’. However, at the same time very specialised ‘know-what’ is often a prerequisite for operating in a science-based learning mode.

Know-how will typically be learnt in apprenticeship-relations where the apprentice follows his master, studies his ‘body language’ as well as his spoken language and relies upon his authority (Polanyi, 1958/1978, p.53 et passim). Know-how is what characterizes a skilled worker and artisan but it is also something that distinguishes the first-rate from the average manager and scientist.

Know-who is also learnt in social practice and some of it is learnt in specialized education environments. Communities of engineers and experts are kept together by reunions, conferences, professional societies, etc. giving the participant access to discussion of experiences and information bartering with professional colleagues (Carter, 1989). It also develops in day-to-day dealings with customers, sub-contractors and independent institutes. Relational learning may contribute both to common codes of information and to social bonds of friendship.

3. Forms of knowledge and modes of learning

The STI-mode

The different types of knowledge may be related to differences in the two modes of learning and innovation we have identified. It will be easier to bring out these relationships if we start by recognising that technologies should be, “understood as involving both a body of practice, manifest in the artefacts and techniques that are produced and used, and a body of understanding, which supports, surrounds and rationalises the former” (Nelson, 2004, p. 457). Some of this understanding takes the form of empirical-based generalisations made explicit by practitioners about what works and what constitute reliable problem-solving methods. Although this kind of know-how may be specific to particular firms, much of it is more generalised knowledge common to wider professional or technical communities who work within the same technological fields.

However, as Nelson (1993, 2004) and others have observed,[3] over the twentieth century most powerful technologies have come to be connected to and supported by different fields of science. One of the stylised facts that emerges from the research on the relation between science and technology is that in most areas the results of scientific research are not directly useful for technological advance.[4] Rather, the contribution of science is usually more indirect. General scientific understanding both "illuminates how artifacts and techniques employed work", thus providing guidance and clues for their further development, and it provides "powerful ways of experimenting and testing new departures" (Nelson, 2004, p. 458).[5] For example, as Pavitt (2005, p. 92) has observed, advances in computing and simulation methods can reduce the costs of search in technological advance by making it possible to explore virtually alternative technical configurations.

Thus, as Brooks (1994, p. 478) notes, technology should be seen as incorporating generic understanding (know-why) which makes it seem like science. Yet it is understanding pertaining to particular artifacts and techniques which distinguishes technology from science. The STI-mode of innovation most obviously refers to the way firms use and further develop this body of science-like understanding in the context of their innovative activities. Over the twentieth century, and still today, a major source for the development of this knowledge about artifacts and techniques has been the R&D laboratories of large industrial firms (Mowery and Oxley, 1995, Chandler, 1977).

The emphasis placed here on the way STI uses and further develops explicit and global know-why and know-what should not be taken to imply an insignificant role for locally embedded tacit knowledge. For instance, scientists operating at the frontier of their fields

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[3] See Pavitt, 2005 and Brooks, 1994.

[4] The notable exceptions are the fields of biotechnology and ICT software, where university research often results in inventions with direct industrial applications. See Mansfield, 1991 and Pavitt and Steinmueller, 2001.

[5] See Price, 1984, for a classic statement.

in the R&D departments of large firms need to combine their know-why insights with know-how when making experiments and interpreting results, and specific R&D-projects will often be triggered by practice, for example problems with new products, processes and user needs. We will still define it as predominately STI because almost immediately attempts will be made to restate the problem in an explicit and codified form. The R&D-department will start going through its earlier work, looking for pieces of codified knowledge, as well as looking for insights that can be drawn from outside sources. In order to communicate with scientists and scientific institutions outside it will be necessary to make knowledge explicit and translate the problem into a formal scientific code. In the empirical section of the paper we use R&D activities and collaboration with scientists attached to universities and research institute as indicators of the STI-mode.

All through the process, documenting results in a codified form remains important. It is not sufficient that the single scientist keeps results in his own memory as tacit knowledge. Often the project involves teamwork and modularization where single results are used as building blocks for other members in the team. At the end of the process – if it is successful - a transfer of the results within the organization or across organizational borders will call for documentation as well. In the case that an application is made for a patent the documentation needs to be made in a techno-scientific language that allows the patenting authority to judge the originality of the innovation.

This means that, on balance, the STI-mode of learning even if it starts from a local problem will make use of 'global' knowledge all the way through and, ideally, it will end up with 'potentially global knowledge' – i.e. knowledge that could be used widely if it were not protected by intellectual property rights. In terms of knowledge management it corresponds well to a strategy of knowledge sharing through wide access to codified knowledge inside the firm. The generalization of the knowledge in the form of a patent and the use of licenses will make it disembodied at least when compared to what comes out of the DUI-mode of innovation.[6]

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[6] There are several caveats to this ideal type of STI-mode of learning. R&D may be oriented to solve very local problems and the results may be kept secret by other means than patents. The most talented scientists will in spite of documentation be carriers of 'personal knowledge' that cannot be easily substituted. There are stories about ASEA – now part of ABB – that an important reason that major breakthroughs were made in strong current technology was a lack of documentation and control that made it possible to have private

The DUI-mode

While science or scientific like understandings have increasingly come to illuminate and support technological practice, it is still the case that, "much of practice in most fields remains only partially understood, and much of engineering design practice involves solutions to problems that professional engineers have learned 'work' without any particularly sophisticated understanding of why" (Nelson, 2004, p. 458). This provides the first hint as to why the DUI-mode is crucial to successful innovation. This kind of knowledge, regardless of the extent to which it is ultimately codified, is acquired for the most part on the job as employees face on-going changes that confront them with new problems. Finding solutions to these problems enhances the skills and know-how of the employees and extends their repertoires. Some of the problems are specific while others are generic. Therefore learning may result in both specific and general competencies for the operator. When the process is complex – a good example is the learning-by-using of new models of airplanes - it will involve interaction within and between teams and it may result in new shared routines for the organization. As the whole organization gets more insight in the actual working of the system it might find more efficient ways to organize work and solve problems as they pop up. This is the kind of case that Rosenberg (1982) uses to illustrate learning-by-using.

Both learning by doing and using normally also involve interaction between people and departments. In particular, an important result coming out of empirical surveys of the innovation process is that successful innovation depends on the development of links and communication between the design department and production and sale (Rothwell, 1977). These links are typically informal and they serve to transmit the tacit elements that contribute to making successful design that can be produced and that respond to user demands. As Lundvall (1992) and others have shown, these links extend beyond the boundaries of the firm to connect relatively small specialised machinery producers and business service providers with their mostly larger clients.

As the above discussion implies, the DUI-mode of learning most obviously refers to know-how and know-who which is tacit and often highly localized. While this kind of

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projects in the desk drawer. And finally the patenting may be seen as the top of the iceberg and as a signal that a lot of tacit knowledge is hidden under the surface.

learning may occur as an unintended by-product of the firm's design, production and marketing activities, the point we want to make here is that the DUI-mode can be intentionally fostered by building structures and relationships which enhance and utilize learning by doing, using and interacting. In particular, organisational practices such as project teams, problem-solving groups, and job and task rotation, which promote learning and knowledge exchange, can contribute positively to innovative performance.

There is a vast business literature on 'high performance work systems' which examines the relation of such organisational practices to enterprise productivity and financial performance in general. (see, for example, Becker and Huselid, 1998; Osterman, 1994, 2000; Ramsay et al., 2000; Wood, 1999). One of the most interesting recent empirical results based on the statistical analysis of national or international survey data is that there is a positive relation between the organisational practices identified in this high performance literature and successful product innovation (Laursen and Foss, 2003; Lorenz et al., 2004; Lorenz and Valeyre, 2006; Lundvall and Nielsen 1999; Michie and Sheenan, 1999).

Since this experience-based learning results in 'local' knowledge, we should not expect it to have any radical impact on the growth of the whole economy. To lift knowledge out of its local context, to generalize it and to make it global there are different mechanisms including learning by interacting, which we regard as part of the DUI-mode of learning (Christensen and Lundvall, 2004). For the economy as a whole *a specific sector* may become the one that through its engagement in processes of interactive learning with a diverse set of users generalizes local knowledge and diffuses it widely in the economy.

Historically, as Rosenberg (1976) has shown, machinery production constituted a strategic sector. Machinery producers addressed many different users and gathered knowledge about their needs and about the performance of different technical solutions. On this basis they developed more global and efficient solutions on the basis of local knowledge and learning. Today we may see similar specialisation and technological convergence with respect to information technology (Pavitt, 2005), and to the role played by *knowledge intensive business service* (KIBS) providers. For the single manufacturing firm it is attractive to outsource certain service functions to specialized KIBS-firms. The KIBS-firm will address several customers and help them to solve their problems in a well-defined field. This gives access to many different processes of local learning taking place under diverse conditions. The KIBS-firm will be able to transform this diversity of experiences into more global and more efficient solutions.

4. The need for a new empirical approach

The importance of both STI and DUI-mode learning for innovative performance is well documented in both the theoretical and the qualitative case study literature on innovation. Yet, when one turns to policy analysis and prescription, as well as to the quantitative survey-based studies which often serve to support and justify policy, we would contend there is a clear bias to consider innovation processes largely as aspects connected to formal scientific and technical knowledge and to formal processes of R&D.

At the European level, this kind of bias can be most easily seen by examining the empirical measures used and the supporting research undertaken for EU-sponsored bench-marking exercises, such as Trendchart.[7] Trendchart's annual ranking of the innovative performance of EU member nations is based largely on conventional S&T measures such as R&D expenditures, patenting, the share of the population with tertiary education, the weight of S&E graduates in the workforce, ICT expenditures and the importance of venture capital. None of the 22 individual measures which are used to construct the 2004 'summary innovation index' for EU member countries are designed to capture organisational aspects linked to informal processes of learning by using, doing and interacting.

A recent Trendchart workshop focusing on the extent of an 'innovation gap' between the EU and the US is representative of the survey-based research supporting such innovation benchmarking exercises. It is notable that the scoping paper for the workshop explains the gap exclusively in terms of R&D expenditures, patenting and the importance of tertiary education.[8]

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[7] See: http://www.trendchart.org/

[8] See: http://trendchart.cordis.lu/ws_paper.cfm?ID=9. While this is obviously not the place to survey the vast amount of literature to be found on the Trendchart website, we would contend that the STI bias will be evident to anyone who takes the time to browse through it.

Of course it can be argued with some justification that this sort of bias in policy and quantitative research reflects the kinds of quantitative measures that are available for comparative research. There now exist internationally harmonised data on R&D, patenting, the development of S&T human resources, ICT expenditures and innovation expenditures more generally, whereas at present there are no harmonised data that could be used to construct measures of learning by doing and using. We would contend, though, that these limitations of the data simply reflect the same bias at a deeper level. The on-going development of harmonised S&T indicators over the post-war period has resulted from political initiatives at the EU and international levels. The lack of DUI measures reflects political priorities and decision-making rather than any inevitable state of affairs.

A final argument seeking to justify the existing bias in quantitative measures is that organisational change and learning processes linked to DUI-mode learning are simply to complex to capture with survey-based methods. While we would agree that the multi-dimensional and multi-level nature of these informal learning dynamics creates problems for measurement that go beyond those confronted in measuring R&D the development of human resources for science and technology, we firmly believe that these can be surmounted. In what follows we propose a set of indicators for DUI-mode learning and we show that the DUI-mode when combined with the STI-mode serves to improve innovative performance.

5. Empirical analysis

Illustrating empirically how DUI and STI-learning promote innovation

In what follows we will show that the probability of successful product innovation increases when the firm has organized itself in such a way that it promotes DUI-learning. We will also show that firms that establish a stronger science base will be more innovative than the rest. But the most significant and important result is that firms using mixed strategies that combine organizational forms promoting learning with R&D-efforts and with co-operation with researchers at knowledge institutions are much more innovative than the rest. *It is the firm that combines a strong version of the STI-mode with a strong version of the DUI-mode that excels in product innovation.*

The empirical analysis is based on a survey addressed to all Danish firms in the private sector – not including agriculture - with 25 or more employees, supplemented with a stratified proportional sample of firms with 20-25 employees. 6991 questionnaires were sent to the firms selected. This survey collected information from management. In total, 2007 usable responses from management have been collected and integrated in a cross section data set. This makes the overall response rate of the survey 29%. A closer response analysis broken down on industries and size show acceptable variations on response rates here, and non-respondent information on some of the potential dependent variables together with comparison to other surveys, do not indicate unacceptable bias.

The survey, which was carried out in 2001 was supplemented in 2004 by additional questions designed to obtain further information on STI-mode learning processes. The sampling frame in the 2004 survey were the 1688 firms from the 2001 survey which were still alive according to the information held by Statistics Denmark. However, of these 1688 firms 45 were unreachable which left us with a sampling frame of 1643 firms. 1141 of these firms answered the second questionnaire, resulting in an impressive response rate for the second questionnaire of almost 70%. The subsequent analysis of the response rates indicates no unacceptable variation within size and industry.

Finally, we have access to register data, allowing us to determine the workforce composition for the relevant firms. As the latent class analysis requires answers to all the questions considered in the analysis, the number of firms available for undertaking this analysis (see Table 2 below) is reduced to 692.

Obtaining a meaningful quantitative measure of innovation and innovative behaviour on the basis of information collected in firms belonging to industries with very different conditions is not unproblematic. The phenomenon that firms refer to may vary in relation to conditions and configurations. Our data indicate that for the most part we are confronted with incremental qualitative change rather than radical change when we ask the firms whether they, in the period of 1998 - 2000, have introduced new products or services on the market. Three fourths of the innovations introduced within the period 1998-2000, were already known at the national as well as well as on the international markets. 13% of the firms have introduced at least one innovation new on the national market, although already existing in world markets. A small group of firms (6%) have introduced at least one innovation new both on the national and the world market.

Developing indicators of STI and DUI-mode learning

Two of three measures we use to capture STI-mode learning are standard measures used to benchmark science and technology development in innovation policy studies: expenditures on R&D; and the employment of personnel with third-level degrees in science or technology. The third measure – cooperation with researchers attached to universities or research institutes – though of recognised importance is less commonly used in policy studies due to the lack of survey data.

For DUI-mode learning the choice of measures is based on a reading of two complementary literatures that deal with the characteristics of ‘learning organisations’: the ‘high performance work system’ literature referred to above (Clegg, et al., 1996; Dertouzos, et. al. 1989; Gittleman et al. 1998; Osterman, 1994, 2000; Ramsay et al., 2000; Truss, 2001; and Wood (1999); and the literature dealing with the relation between organisational design and innovation (Burns and Stalker, 1961; Mintzberg, 1979; Lam, 2005). Both of these literatures draw a distinction between relatively bureaucratic or rigid organisations and those with a greater capacity for learning and innovative response, though the latter has tended to develop somewhat more elaborate typologies of organisational forms. The ‘high performance’ literature focuses on the diffusion of specific organisational practices and arrangements that enhance the firm’s capacity for responding to changes in markets and technology. These include practices designed to increase employee involvement in problem-solving and decision-making such as autonomous teams, problem-solving groups and systems for collecting employee suggestions. The first four of our six indicators of DUI-mode learning measure whether or not the firm makes use of the core high-performance work practices.

A similar contrast between rigid and adaptable organisations can be seen in Burns and Stalker’s (1961) distinction between ‘mechanistic’ and ‘organic’ organisations, or in Mintzberg’s (1979) distinction between the ‘machine bureaucracy’ and the ‘operating adhocracy’. Lam (2005) also distinguishes between rigid and flexible organisations while making a further distinction between two relatively flexible organisational forms that support learning and innovation: the ‘operating adhocracy’ and the ‘J-form’. The term J-form is used because its archetypical features are best illustrated by the ‘Japanese-type’ organisation discussed in the work of Aoki (1988) and Nonaka and Takeuchi (1995). In order to capture the difference between relatively hierarchical and rigid organisations on the one hand, and the more flexible and decentralised structure of learning organisations on the other, we included a measure of the extent to which functions are integrated and a measure of the extent to which demarcations are softened.[9]

[9] In Appendix 1 the exact formulation of the questions and the distribution of the answers can be found.

Table 1: Indicators of DUI and STI-mode Learning

Indicators	
DUI-mode learning	
Interdisciplinary workgroups	1 if the firm makes some use of interdisciplinary groups, 0 otherwise
Quality circles	1 if the firm makes some use of quality circles, 0 otherwise
Systems for collecting proposals	1 if the firm makes some use of systems for collective proposals, 0 otherwise
Autonomous groups	1 if the firm makes some use of autonomous groups, 0 otherwise
Integration of functions	1 if the firm makes some use of integration of functions, 0 otherwise
Softened demarcations	1 if demarcations between employee groupings have become more indistinct or invisible during 1998-2000, 0 if they are unchanged or have become more distinct
Cooperation with customers	1 if the firm has developed closer cooperation with customers during 1998-2000 to a high extent, 0 if to a small or medium extent or not at all
STI-mode Learning	
Expenditures on R&D as share of total revenue	1 if the firm's expenditures on R&D are positive, 0 otherwise
Cooperation with researchers	1 if the firm cooperates with researches attached to universities or scientific institutes rarely, occasionally, frequently or always, 0 if it never engages in these forms of cooperation
Indicator for workforce composition	Register data indicating whether a firm employs scientifically trained personal[10]. 1 if the firm employs scientifically trained personal, 0 otherwise

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[10] Scientifically trained personal includes bachelors, master and Ph.D. students within the natural sciences as well as civil engineers.

In order to find out how the different DUI-measures are combined with the capacity to handle scientific and codified knowledge we have pursued a clustering across firms using latent class analysis. Latent class analysis can be seen as an alternative to the more familiar cluster analysis methods e.g. methods based on proximity measures of the observations. For an elaborate review see e.g. Hagenaars og McCutcheon (2003). The latent class analysis is able to cope with data that are measured on a nominal or ordinal measurement scale. In addition the technique is based on a statistical model such that the goodness-of-fit of the model can be measured and tested. The outcome of the latent class analysis consists of the conditional probabilities for implementing a particular practice given that the firm is from a particular cluster. In addition it is possible to estimate the cluster membership given a firm has implemented a particular set of practices. The latter is used in the logistic analysis further ahead. Table 2 below presents the results as they come out when the 4-cluster solution is used and in Appendix 2 the goodness of fit of the model is shown together with the results of an alternative 5-cluster solution. The percentage figures presented in Table 2 show the probability that a firm in a particular cluster is characterised by a practice or policy:

Table 2: Clustering of 692 Danish firms based on latent class analysis: probability that a firm will be characterised by a policy/practice according to cluster

	Low learning	**STI Cluster**	**DUI Cluster**	**DUI/STI Cluster**	**All firms**
Makes use of interdiscipl workgroups	0.1155	0.0143	0.5448	0.9888	0.3960
Makes use of quality circles	0.0159	0.2670	0.5054	0.5483	0.2890
Makes use of systems for proposals	0.1481	0.3554	0.6253	0.5757	0.3931
Makes use of autonomous groups	0.2145	0.4427	0.5320	0.6139	0.4090
Makes use of integration of functions	0.1346	0.2254	0.5545	0.6392	0.3642
Demarcations more indistinct/invisible	0.2709	0.4879	0.5671	0.6256	0.4494
Cooperation with customers high	0.2582	0.4292	0.5512	0.4970	0.4090
R&D expenditures positive	0.1002	0.9875	0.2977	0.8742	0.4017
Cooperation with researchers positive	0.1088	0.8586	0.2195	0.9550	0.3829
Employs scientifically trained personal	0.0854	0.3544	0.1091	0.6826	0.2341
Percentage distribution of firms across clusters	0.4050	0.1099	0.2974	0.1877	1.0000

The first cluster is a static or low learning cluster. It brings together firms that neither have highly developed forms of organizations that support DUI-learning nor engage in activities that indicate a strong capacity to absorb and use codified knowledge. The low learning cluster encompasses firms that do not spend on R&D nor cooperate with researchers. The latter may be explained by the fact, that these firms have a low probability of employing scientifically trained personal.

The second cluster, which we refer to as the STI cluster, encompasses about ten percent of the firms. Firms belonging to the STI cluster have activities that indicate a strong capacity to absorb and use codified knowledge. However, the firms in the STI cluster have rarely implemented organizational characteristics typical for the learning organization. The STI Cluster includes firms that have established the STI-mode without combining it with the DUI-mode.

The third cluster, which we refer to as the DUI cluster, brings together about one third of the firms in a group that is characterized by an over-average development of organizational characteristics typical for the learning organization but without activities that indicate a strong capacity to absorb and use codified knowledge. The firms in this cluster have a low probability of employing scientifically trained personal and their cooperation with researchers attached to universities or research institutes is below-average. This cluster includes firms that have introduced elements of the DUI-mode but are weak in terms of using the STI-mode

The fourth cluster includes firms using mixed strategied that combine the DUI and STI modes. It includes one fifth of the firms and these firms tend to combine the characteristics indicating a strong capacity for informal experience-based learning with activities that indicate a strong capacity to absorb and use codified knowledge.

These outcomes of the latent class analysis are interesting. They indicate that quite a number of firms that operate in economic activities where scientific and codified knowledge are important have also adopted organisational practices designed to promote knowledge exchange, problem-solving and learning amongst their employees (DUI/STI Cluster). But there are also a number of firms in the STI cluster where knowledge flows exist between the firm and external partners with over 95 percent spending on R&D and more than 85 percent cooperating with researchers but where there is little evidence of the practices designed to promote employee learning and problem-solving. Finally, the share of firms belonging to the DUI Cluster is quite high. Hence there exists a significant group of firms that might well be transformed so as to acquire the characteristics of the combined DUI/STI cluster. Below we present evidence that indicates that such a transformation might stimulate innovation.

Table 3 shows the frequency distribution of the different clusters by firm size, industry, group ownership and production. It is clear that the different clusters are distributed unevenly across industry, size and ownership. In terms of size, it is not surprising to find that relative to the population average the smallest firm size category is overrepresented in the low learning cluster. The other result that stands out is the marked overrepresentation of the 100 and over employee size category in the combined STI/DUI cluster. The mid-range 50-99 employee category is somewhat overrepresented in the stand alone STI and DUI clusters. In terms of sector, it is not surprising to find that construction, trade and other services, are underrepresented the STI and DUI/STI clusters given the relatively low levels of R&D expenditure that characterise these sectors. Foreign groups tend to be overrepresented in the STI and DUI/STI clusters suggesting that they are characterised by relatively high levels of R&D and relatively well developed links with universities or research institutes. Single firms, on the other hand, tend to be underrepresented in these two clusters. The frequency distribution of the standard and customised product categories across the clusters tends to conform to the population averages with the exception that the standard product category is slightly overrepresented in the STI cluster.

Table 3: The frequency of the three clusters by firm size, sector, group ownership and production type (percent horizontal)

Variables:	Low Learning	STI Cluster	DUI Cluster	DUI/STI Cluster	*N*
Less than 50 employees	0.5605	0.0855	0.2566	0.0973	*339*
50 - 99 employees	0.3314	0.1775	0.3018	0.1893	*169*
100 and more employees	0.2457	0.1257	0.2686	0.3600	*175*
Manufacturing, high tech	0.2231	0.2645	0.2314	0.2810	*121*
Manufacturing, low tech	0.3522	0.1321	0.2893	0.2264	*159*
Construction	0.6139	0.0495	0.2574	0.0792	*101*
Trade	0.5780	0.0462	0.3064	0.0694	*173*
Business service	0.2727	0.0909	0.2576	0.3788	*66*
Other services	0.6512	0.0465	0.2791	0.0233	*43*
Danish group	0.4073	0.1371	0.2460	0.2097	*248*
Foreign group	0.2903	0.1694	0.2903	0.2500	*124*
Single firm	0.4890	0.0789	0.2776	0.1546	*317*
Standard product	0.3574	0.1687	0.2851	0.1888	*249*
Customized product	0.4518	0.0871	0.2635	0.1976	*425*
All firms	0.4249	0.1171	0.2673	0.1908	*692*

In order to examine the effect of the learning modes on the firm innovative performance we use logistic regression analysis as reported in Table 4. The dependent variable for this exercise is whether or not the firm has introduced to the market a new product or service (P/S innovation) over the last three years. The independent variables in the Model 1 specification are binary variables indicating whether or not the firm belongs to a particular cluster. In the Model 2 specification we include control variables to account for the effects of industry, firm size, ownership structure, and whether the firm produces customised or standard products.

Table 4: Logistic regression of learning clusters on product/service innovation

	Model 1 *(without controls)*		Model 2 *(with controls)*	
Variables	Odds ratio estimate	Coefficient estimate	Odds ratio estimate	Coefficient estimate
STI Cluster	3.529	1.2611**	2.355	0.8564**
DUI Cluster	2.487	0.9109**	2.218	0.7967**
DUI/STI Cluster	7.843	2.0596**	5.064	1.6222**
Business services			1.433	0.3599
Construction			0.491	-0.7120*
Manufacturing (high			1.805	0.5905*
Manufacturing (low			1.250	0.2229
Other services			0.747	-0.2923
100 and more			1.757	0.5635*
50-99 employees			0.862	-0.1481
Danish group			0.859	-0.1524
Single firm			0.521	-0.6526*
Customised product			1.378	0.3203
Pseudo R^2	0.1247	0.1247	0.1775	0.1775
N	*692*	*692*	*692*	*692*

** = significant at the .01 level; * = significant at the .05 level

Using the static or low learning cluster as benchmark, the Model 1 results without controls show that the probability of introducing a new product or service to the market for firms belonging to the DUI-cluster this more than twice as high, while for the STI cluster the probability is more that three times. The difference is significant for both clusters. We find an almost 8 times as high a chance of P/S-innovation for the combined DUI/STI cluster firms and here the difference is also highly significant. [11]

When we add the control variables to account for the effects of size, sector, ownership and product type (Model 2), the difference observed in the probability of P/S innovation between the STI and DUI clusters disappears. For firms grouped in the combined DUI/STI cluster, the probability of innovating decreases substantially to approximately five times as high as for those grouped in the low learning cluster. In the case of the STI cluster, the difference between the Model 1 and Model 2 results can most plausibly be accounted for by this cluster's overrepresentation in the high tech sector, which has a positive and significant impact on the probability of innovation, and its under representation in the construction and single firm categories, both of which have negative and significant impacts on the probability of innovation. For the combined DUI/STI cluster the decrease in the size of the odds ratio estimate in the Model 2 results can similarly be explained by this cluster's overrepresentation in the high tech category and its under representation in construction. A further factor is the overrepresentation of the DUI/STI cluster in the 100 and over employee firm size category which has a positive impact on the probability of innovation.

Overall, the results of the logistic analysis show that adopting DUI-mode enhancing practices and policies tends to increase firm innovative performance. Further, they support the view that firms adopting mixed strategies combining the two modes tend to perform better than those relying predominately on one mode or the other.

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[11] There may, of course, be reverse causality involved in these results in the sense that firms that succeed in innovating are better able and motivated to introduce DUI organisational traits and invest in R&D. This sort of problem, however, applies for any study that relies on cross-sectional data. What we show here is, simply that some sets of firm characteristics are good predictors of innovative performance.

6. Conclusion: implications for innovation analysis and policy

Our empirical analysis indicates the existence in the Danish economy of both DUI and STI firms. The indication is a bit stronger for the STI mode but we can also discern a group of firms that have introduced DUI-mode practices without connecting strongly to external research and without engaging in R&D.

One of the areas where the explicit distinction between the two modes of learning may be of special interest is the study of innovation systems (Freeman 1987, Lundvall 1992, Nelson 1993, Edquist 1997). One common assumption behind the idea of innovation systems is that elements of knowledge important for economic performance are localized and not easily moved from one place to another. It is obvious that in a fictive neoclassical world where knowledge was identical to information and where society was populated with perfectly rational agents, each with unlimited access to information, national innovation systems would be a completely unnecessary construct. In this sense there is an implicit assumption that some of the learning in a system of innovation takes place in the DUI-mode.

Further, recognizing and analysing the co-existence, co-evolution and synergies between the DUI and STI-modes more systematically may represent progress in innovation theory. It might correspond to how the ‘innovation as an interactive process’-perspective overcame the traditional split between those who argued that supply-side factors were most important and those arguing that demand factors determine the rate and direction of innovation.

In this respect, is important to note that the two modes of learning and innovation, though present to a greater or lesser degree, do not exclude each other. Actually elements of both are present in all business activities in sectors where innovation is an option. Any strategy to promote innovation needs to take both of these sources of innovation into account. While the STI-mode may be of marginal importance in some informally organized businesses the firms that use the STI-mode most intensely will be highly dependent on the successful organization of the DUI-mode.

Our cluster analysis indicates that many firms that are involved in STI-learning have established organizational elements related to the DUI-mode. They will operate in sectors where there is supply-driven and sometimes radical change in products and processes. To cope with these changes the need for learning by doing, using and interacting will be strongly felt. Likewise, for firms in traditional sectors it is no longer sufficient to base competitiveness on know-how and DUI-learning. Firms that connect more systematically to sources of codified knowledge may be able to find new solutions and develop new products that make them more competitive. Moreover, the cluster analysis shows that what really improves innovation performance is using mixed strategies that combine strong versions of the two modes.[12]

That the two modes of learning co-exist and can be made to complement each other doesn't necessarily mean that they are always in harmony with each other. Sometimes there may be contradictions between them, which have to be tackled before potential benefits could be reaped. The STI-mode calls for codification and for codes that are general while the DUI-mode tends to thrive on the basis of implicit and local codes. It is a major task for knowledge management to make strong versions of the two modes work together in promoting knowledge creation and innovation.

Our results strongly suggest that firms with an exclusive focus on developing their science and technology base are foregoing important gains that could be reaped by adopting practices and measures designed to promote informal learning by using and doing. This has major implications for benchmarking innovation systems and for innovation policy. As we have observed, in the current European 'innovation scoreboard' there is a strong bias toward indicators that reflect the STI-mode while those referring to the DUI-mode are absent. Our results clearly point to the need to develop harmonised indicators of the DUI-mode to arrive at an adequate understanding of the bases for differences in innovative performance.

Correspondingly it also implies the need for a realignment of policy objectives and priorities, given the tendency to develop innovation policy with a one-sided focus on

[12] These results are consistent with the presence of complementarities between the sets of practices making up the two modes but are not sufficient to demonstrate such complementarity. Demonstrating complementarity between the two modes would require showing that using to a greater extent the practices making up one mode increases the returns from using to a greater extent the practices making up the other. For a useful discussion of the different statistical approaches that have been used to test for the presence of complementarity among a group of variables, see Galia, et al. (2004, pp. 1191-1192).

promoting the science-base of high-technology firms. Equally, it suggests that too little attention is being given to policies that serve to strengthen linkages to sources of codified knowledge for firms operating in traditional manufacturing sectors and services more generally.

Thinking in terms of the two modes and their evolution in the learning economy may also have implications for wider aspects of public policy and institution building. Education may prepare students to work with specialized global codes in the different disciplines as well as involve them in learning to develop and use local codes through problem-based learning. The design of intellectual property rights and of labour contracts might need to strike a balance between the two modes. Organising innovation policy and distributing responsibility between, for instance, ministries of education, science, industry and economic affairs needs to balance the two modes in innovation policy.

It is our contention that applying the STI- and DUI-modes of learning to innovation systems and to analyse how they co-evolve is a way to clarify and further develop this concept. This is true not only for national systems but also for sectoral, technological and regional systems (Breschi and Malerba 1997; Carlsson and Jacobsson 1997; Maskell and Malmberg 1997). Our empirical analysis demonstrates, not surprisingly, that the modes are applied with different weights in different sectors and this implies that regional specialisation and clustering will make them appear differently also in geographical space.

Of course in the context of this paper we can only hint at these possible consequences of our framework. Our main objective has been to demonstrate the usefulness of the conceptual distinction between the DUI- and STI-modes of learning and to demonstrate that these concepts can be made operational. If we have succeeded at that task we are confident that future research will take up the wider implications for institution-building in the learning economy

Appendix 1. The questions used in the survey.

	Original coding in the questionnaire						N	Coding used in this paper		N
Does the firm make use of some of the following ways of planning the work and paying the employees?	Yes	No	Don't know					Yes	No	
Interdisciplinary workgroups	38.12%	59.47%	2.41%				1907	39.60%	60.40%	692
Quality circles/groups (Formal delegation of quality control)	28.14%	68.03%	3.83%				1905	28.90%	71.10%	692
Systems for collecting proposals from employees	37.79%	59.07%	3.14%				1913	39.31%	60.69%	692
Autonomous groups	41.35%	56.36%	2.29%				1925	40.90%	59.10%	692
Integration of functions (e.g. sales,production)	33.63%	59.41%	6.96%				1897	36.42%	63.58%	692
How have the demarcations between the employee groupings within production/service (main field) developed during 1998-2000? Are they	More distinct	More indistinct	Invisible during the period	Invisible before the period	Remain unchanged	Only one occupational group in production/ service		More indistinct + Invisible during the period + Invisible before the period	More distinct + Remain unchanged	
	5.98%	30.57%	2.10%	3.27%	45.71%	12.37%	1956	44.94%	55.06%	692
To which extent has the firm developed a closer co-operation with the following actors during 1998-2000?	High extent	Some extent	Small extent	Not at all	Don't know	Not relevant		High extent	Some extent + Small extent+ Not at all	
Customers	39.75%	46.77%	8.35%	2.65%	0.87%	1.63%	1965	40.90%	59.10%	692
How large a share of total revenue did expenditure on R&D constitute	0%	0-2%	3-5%	6-15%	Above 15%	Don't know		0-2% + 3-5% + 6-15% + Above 15%	0%	
	59.17%	20.00%	7.93%	3.69%	1.47%	7.74%	1085	59.83%	40.17%	692
How often does the firm cooperate with researchers attached to universities of scientific institutes	Never	Rarely	Occasionally	Frequently	Always	Don't know		Rarely + Occasionally + Frequently + Always	Never	
	63.41%	19.46%	10.85%	3.41%	0.72%	2.15%	1115	61.71%	38.29%	692

Appendix 2. The goodness of fit of the model

Table A 2. 1 Summary statistics from the latent class analysis

Solution	BIC(L^2)	AIC(L^2)	p-value
2-cluster	-3471.06	-515.788	0
3-cluster	-3491.35	-527.002	0.502
4-cluster	-3535.77	-503.201	0.288
5-cluster	-3396.10	-513.462	0.432

The choice between the various solutions is determined by the fit of the model to the data, the Bayesian information criteria, BIC, the Akaike information criteria, AIC, and the interpretability.

To examine the fit of the model we test the null hypothesis, which states that each model fits the data whereas the alternative hypothesis states that the model involved does not fit the data. The test is a standard chi-squared test, well known from the analysis of contingency tables. From table A 1 above we see that a 3-cluster, 4-cluster as well as a 5-cluster solution all fit the data as the p-values are well above 0.1.

With respect to the information criteria we have a mixed pattern. From the literature it is well known that that the BIC criteria is too conservative with respect to the number of classes, whereas the AIC is known to be too liberal, see e.g. McLachlan and Peel (2000). Therefore we have chosen to report both. We see that the BIC points towards a 5-cluster solution, whereas AIC indicates that a 4-cluster solution is the most appropriate. Thus, the information criteria do not unequivocally identify the most appropriate solution.

Therefore the interpretability becomes the decisive criteria. In table A 2 we have reported the 5-cluster solution. It is possible to identify a low learning, a STI, a DUI, and a STI/DUI cluster I the 5-cluster solution. However, the fifth cluster is a mixture of cluster 3 and 4 (DUI/STI and STI). All things considered we decided to use the 4-cluster solution, which will be the premise for the analysis.

Table A 2.2. The 5-cluster solution.

	Cluster 1	**Cluster 2**	**Cluster 3**	**Cluster 4**	**Cluster 5**
Makes use of int.discip. workgroups	0.5454	0.1156	0.9913	0.1072	0.0103
Makes use of Quality circles	0.4909	0.0253	0.5560	0.0124	0.3387
Makes use of systems for proposals	0.6254	0.1913	0.5762	0.0096	0.4491
Makes use of autonomous groups	0.5244	0.2609	0.6198	0.0713	0.5723
Makes use of integration of functions	0.5557	0.1511	0.6456	0.0833	0.2450
Demarcations more indistinct/invisible	0.5602	0.3017	0.6301	0.1864	0.5811
Cooperation with customers high	0.5492	0.2497	0.4969	0.2718	0.4840
R&D expenditures positive	0.3196	0.0061	0.8811	0.4700	0.9930
Cooperation with researchers positive	0.2378	0.0250	0.9616	0.4168	0.9082
Employs scientifically trained personal	0.1274	0.0362	0.6900	0.2589	0.3202
Percentage distribution of firms across clusters	0.3079	0.3018	0.1803	0.1261	0.0840

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