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KNOWLEDGE AND LEARNING IN THE DETERMINATION OF THE OPTIMAL FORM OF FIRM ORGANISATION

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ABSTRACT: This study examines the optimal form of a firm's organisation. Specifically, it discusses the efficient degree of labour specialisation in a firm. Specialisation of labour improves labour productivity through learning-by-doing. The problem of organisation arises, however, from the fact that the actions of specialised workers need to be coordinated in order to achieve gains from cooperation. Therefore, coordination costs may limit returns to specialisation. Moreover, changes in technology or workers' human capital may change the returns to learning in favour of less specialisation.

The thesis compares theoretically the relative efficiency of organisations, which feature different degrees of labour specialisation. The comparison is made by showing how learning and communication take place in different organisational structures, and how the costs and returns to these activities vary. The optimal degree of labour specialisation under different conditions is then derived.

The model of Lindbeck and Snower (2000) addresses the efficient form of work organisation in terms of the degree of labour specialisation by work task. It examines when it is worthwhile to have workers specialising by task and when they should perform multiple tasks. It finds that it is optimal for workers to perform multiple tasks only if performing different tasks is sufficiently complementary to each other. As a result, the returns to task integration outweigh the returns to specialisation. Moreover, exogenous changes in technology or human capital may change the relationship of these returns in favour of one or the other type of organisation.

The second model from Greenan and Guellec (1994) compares a centralised and a decentralised organisation focusing on the coordination of learning-by-doing among workers. It takes communication costs into account because learning requires information sharing among workers. A decentralised organisation is associated with low costs of producing knowledge and high communication costs, whereas the opposite holds for the centralised organisation. It turns out that the optimal organisational form depends on the size of the labour force. Furthermore, the relative efficiency of the two organisation styles may change in favour of decentralisation when product differentiation in the economy grows.

KEY WORDS: organisation theory, knowledge, learning, labour specialisation
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Tämä tutkielma käsittelee yrityksen optimaalista organisaatiomuotoa, tarkemmin ottaen optimaalista työvoiman erikoistumisastetta yrityksessä. Työvoiman erikoistuminen parantaa työn tuottavuutta tekemällä oppimisen (learning-by-doing) kautta. Työn organisoimisen ongelma on kuitenkin se, että erikoistuneiden työntekijöiden toiminta pitää koordinoida, jotta yhteistyön edut voidaan saavuttaa. Siten koordinaatiokustannukset voivat rajoittaa erikoistumisen tuottoja. Lisäksi teknologian tai inhimillisen pääoman muutokset voivat muuttaa oppimisen tuottoja tehtävien integroimisen suuntaan erikoistumisen sijaan.

Tutkielmassa vertaillaan teoreettisesti erilaisten organisaatioiden suhteellista tehokkuutta sen mukaan, kuinka erikoistunutta työvoima on. Keskeisellä sijalla on se, miten oppiminen ja kommunikaatio on organisoitu erilaisissa organisaatiomalleissa ja miten oppimisen ja kommunikaation tuotot ja kustannukset vaihtelevat. Optimaalinen työvoiman erikoistumisaste eri olosuhteissa johdetaan tämän analyysin perusteella.

Ensimmäinen käsiteltävä malli pohjautuu Lindbeckin ja Snowerin (2000) artikkeliin. Mallissa vertaillaan kahta organisaatiomuotoa, joissa on vastakkaiset työvoiman erikoistumisasteet. Mallissa tutkitaan sitä, milloin työntekijöiden kannattaa erikoistua tehtävien mukaan ja milloin heidän pitäisi suorittaa useampia tehtäviä. Tuloksena on se, että työntekijöiden on optimaalista suorittaa useampia tehtäviä silloin, kun nämä tehtävät ovat komplementaarisia toisilleen. Tällöin tuotot tehtävien integroimisesta ovat suuremmat kuin tuotot erikoistumisesta. Lisäksi eksogeeniset muutokset teknologiassa tai inhimillisessä pääomassa voivat muuttaa näiden tuottojen suhdetta.

Toinen, Greenanin ja Guellecin (1994) malli vertaa keskitettyä ja hajautettua organisaatiota keskittyen tekemällä oppimisen koordinointiin. Mallissa huomioidaan myös kommunikaatiokustannukset, koska oppiminen edellyttää kommunikaatiota työntekijöiden välillä. Hajautetussa organisaatiossa tiedon tuotantokustannukset ovat matalat mutta kommunikaatiokustannukset korkeat. Keskitetyssä organisaatiossa tilanne on taas päinvastoin. Mallissa näytetään, kuinka optimaalinen organisaatiomuoto riippuu työvoiman koosta. Lisäksi näiden kahden organisaatiomuodon suhteellinen tehokkuus voi muuttua talouden tuotedifferentaation kasvaessa.

AVAINSANAT: organisaatioteoriat, tieto, oppiminen, työvoiman erikoistuminen

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Non-technical summary

This study examines theoretically the optimal form of firm organisation, specifically, the optimal degree of labour specialisation within a firm. The topic is an actual one because today we hardly ever find an organisation, where workers are strictly specialised by task. Instead, the degree of labour specialisation may be low, as firms often use management practices such as group work or job rotation, whereby the tasks one worker performs become varied. Therefore, this study examines what is the optimal degree of labour specialisation in a firm and under which conditions.

In the first half of this century manufacturing plants were designed by the guidelines of Fordism or Taylorism. In a stereotypic Fordist factory large batches of highly standardised products are produced in long production lines. Taylorism is largely complementary to Fordism, it proposes that work tasks should be split into small, simple elements. One worker will then specialise into performing only one of these small elements. The efficiency of these types of production and management styles are derived from economies of scale and large product batches. However, it has been questioned, whether these sources of efficiency are being replaced by efficiency derived from a large variety of products and quick response to changing consumer demands. As a result, a different kind of organisational style may also be needed, which relates to the growing role of production workers in the management of production (e.g. flattening of hierarchical organisation structures, increasing use of teamwork, continuous learning).

This study concentrates on the theoretical understanding of organisational change. It questions, whether the returns to labour specialisation may be limited in some environments. Specialisation of labour increases labour productivity, because returns to time spent on tasks are usually greater to workers who concentrate on a small range of skills. This happens through learning-by-doing, which implies increasing productivity of labour at a task with time spent on that task. However, changes in technology and human capital may change the returns to learning in favour of task integration instead of specialisation by task. Productivity at a task may be improved from experience gained in other tasks even though this means less time and less learning-by-doing in the initial task.

Learning has also a collective dimension within the firm, since workers can make use of information accumulated somewhere else in the organisation. Hence, coordination of workers is needed in the efficient organisation of work. In the traditional, hierarchical manufacturing organisation workers mechanically perform their tasks, whereas the coordination of work is left to a higher organisational level. As a result, in a hierarchical organisation communication is minimised as information flows only vertically and a mess of horizontal information flow is avoided. However, when workers have to process information and communicate it onwards, this type of vertical coordination may be very costly. Instead, it may be efficient to have workers react to new information and adjust their work practices accordingly. This leads to less specialisation of labour, as the traditional demarcations between worker and manager functions weaken. As a result, also high communication costs may limit the returns to specialisation of labour on the organisation level.

In sum, this study shows how organisational forms, which differ in terms of their degree of labour specialisation, are associated with different ways of organising learning and communication and thereby also different costs and returns to these activities. The relative effi-

ciency of an organisational form is a result of balancing these returns and costs with respect to the economic environment of the firm. The theoretical models considered in this study compare two organisations with opposing degrees of labour specialisation. The models show that changes in technology or workers' human capital may increase the returns to learning across tasks relative to returns to learning-by-doing in specialised tasks. Therefore, an organisation with a small degree of labour specialisation may be optimal. Furthermore, it is shown that the optimal organisational form depends on the size of the labour force. Finally, the relative efficiency of the two organisation styles may change in favour of decentralisation when the differentiation of products grows.

1 INTRODUCTION

1.1 Background to the thesis

The existing economic literature has addressed the question of the process of reorganisation of work in firms in industrialised countries (e.g. Milgrom - Roberts 1990; Lindbeck - Snower 2000; Piore - Sabel 1984; Böckerman 1996). Firms' work organisations resemble less and less the traditional industrial firm organised along Fordist[1] or Tayloristic[2] lines. The central idea of Fordism is to achieve as low unit costs as possible by utilising economies of scale. Therefore, in a stereotypic Fordist factory large batches of highly standardised products are produced in long production lines. The purpose of Taylorism is complementary to that of Fordism. According to Taylorism, efficiency is maximised by carefully splitting tasks into small, simple, carefully defined elements. One worker will then specialise in performing only one task, and physical capital is also designed for this single function. A hierarchical work organisation is closely associated with this kind of specialisation of operations. (Böckerman 1996, 42; Lindbeck - Snower 2000.)

The development in firms' work organisations in the past couple of decades suggests, however, that the mass production firm is losing its significance. Firms may no more be able to rely on a small and standardised product variety, as consumers' preferences are becoming increasingly versatile and volatile. For example, the only car model Ford transfer lines could produce was a black Model T. The entire factory had to be rebuilt when the product design was changed. Examples of the other extreme are often found in the Japanese automobile industry. In each Toyota assembly line, thousands of variants of several basic designs are produced, to match customers' individual orders (Milgrom - Roberts 1995). Therefore, efficiency derived from producing large batches of few standardised products is being replaced by efficiency derived from a large variety of products and quick response to changing consumer demands.

Whereas the hierarchical work organisation fits well into the Fordist or Tayloristic firm featuring advanced labour specialisation, the efficient work organisation of a firm following a different production logic may also be different (Milgrom - Roberts 1990, 513). A growing body of evidence shows that firm organisations are becoming less hierarchical, and labour, as well as physical capital are becoming less specialised. The introduction of flexible and programmable machinery enables using physical capital in several functions, and labour is enabled to be more versatile, too. In the business world, this organisational restructuring can be observed in the introduction of managerial innovations such as *lean production*[3] and *just-in-time production*[4]. The central organisational ideas behind them arise from the growing role of production workers in the management of production: flat-

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1 Referring to the work organisation introduced in the famous Ford car factories in the beginning of the 20th century.

2 Referring to Frederick Taylor, the frontrunner in the scientific management of firms (Taylor 1913).

3 In a production system based on *lean production* all excess hierarchy levels are removed and workers are given more responsibility (Böckerman 1996, 46).

4 *Just-in-time production* relies on close communication and tight coordination between successive stages of production, so that each stage would be informed "just in time" when it had to deliver its product to the next stage. Therefore, the system minimises inventories from the production process. (Milgrom - Roberts 1992, 5.)

tening of hierarchical organisation structures, decentralisation of responsibility, increasing use of teamwork, and continuous learning.

These organisational changes have received considerable attention in management and business literature, but also increasingly in the field of economics. Various empirical studies have been conducted on the topic especially in the U.S., ranging from case studies to intra-industry or nationwide studies (for a review, see Ichniowski et al. 1996; OECD 1999). Many of these studies report a growing frequency of organisational changes. In the Nordic context, a study covering four Nordic countries found that the majority of establishments with more than 50 employees moved to a more decentralised work organisation in the 1990s (NUTEK 1999, 114-115).

1.2 Research problem

This Master's thesis concentrates not on the empirical dimensions of organisational change, but on the theoretical rationale and understanding of it. The advantages of specialisation of labour have been known since the well-known work of Adam Smith, who described the benefits of the division of labour at length in "Wealth of Nations" (1776). A more extensive division of labour raises productivity because returns to time spent on tasks are usually greater to workers who concentrate on a narrower range of skills (Becker - Murphy 1992). However, the returns to specialisation may be limited because of high costs associated with processing and communicating information in a hierarchical organisation. Moreover, changes in technology and human capital may change the returns to learning in favour of task integration instead of specialisation by task. As a result, the traditional hierarchical form may not be the optimal way to organise work.

This thesis examines the determination of the optimal form of firm organisation. Specifically, the focus is on the organisation of labour within firms, that is, the degree of labour specialisation. The concept of labour specialisation is inherently connected to the returns to learning, as Adam Smith implied. Learning improves the productivity of labour as workers utilise acquired knowledge on production to become more skilful in their tasks. Moreover, learning has a collective dimension within the firm, since workers can also make use of information accumulated somewhere else in the organisation. On the other hand, learning and sharing of knowledge necessarily take time, which makes them costly activities.

This thesis shows how different organisational forms affect the way learning and communication take place, and how the costs and returns to these activities are thereby affected. Therefore, the optimal organisation form takes into account both the returns and costs associated with learning and communication. The theoretical models discussed refer to organisational forms with different degrees of labour specialisation, and the optimal degree of labour specialisation under different conditions is then derived. It is important that this will be a result of the efficient way to organise work, given the returns and costs associated with learning and communication.

Optimal organisational forms are examined on the basis of two theoretical models. The first model of Lindbeck and Snower (2000) addresses the efficient form of work organisation in terms of the degree of labour specialisation by work task. It examines when it is worthwhile to have workers specialising in one task and when they should perform multiple tasks. The crucial feature is learning *within* and *across* tasks. The relative returns to these two kinds of learning then determine the optimal form of organisation.

The second model of Greenan and Guellec (1994) addresses firm organisation through coordination of learning-by-doing. It recognises that learning is essentially a collective phenomenon within firms, because communication is a central aspect of knowledge accumulation within the firm. The model shows how different styles of organising labour within firms correspond to different styles for coordinating learning-by-doing and communication.

Therefore, both models address how learning takes place within an organisation and how different types of organisational forms are associated with different returns to learning. The research problems this thesis thus seeks to find answers to are: What is the optimal way to organise work in a firm, particularly, what is the optimal degree of labour specialisation and under which conditions? How do learning and communication enter this analysis? How do different ways of organising learning and communication affect the optimal degree of labour specialisation?

1.3 Structure of the thesis

This thesis is divided into five sections. Chapter 2 reviews shortly economic theory on organisations focusing on the topic of this thesis: learning, communication and the division of labour in organisations. The analytical model of Lindbeck and Snower (2000) is then examined in chapter 3. This model was chosen because it addresses the optimal degree of labour specialisation in firms presenting two opposite types of organisations: specialisation and non-specialisation of labour. The model finds that the optimal degree of labour specialisation depends on the returns to specialisation by task relative to the returns to complementarities between different tasks. It is optimal for workers to perform multiple tasks only if the returns to task complementarities outweigh the returns to specialisation. In addition, the analysis finds that these returns to task complementarities may increase as a result of technical change and changes in workers' human capital.

The efficient coordination style for information processing and communication is examined in chapter 4, in the model of Greenan and Guellec (1994). The reason this model was chosen was that it also presents two opposing organisational forms, a centralised and a decentralised one, and it explores their relative efficiency. In the centralised organisation access to knowledge is restricted to only some workers. Hence, the amount of learning-by-doing is minimised. In the decentralised organisation, on the other hand, all workers participate in learning-by-doing: they create new knowledge and communicate it onwards. It turns out that the optimal organisational form depends on the size of the labour force. In a small firm the decentralised organisation is optimal, whereas in a large firm the centralised organisation is optimal. Finally, chapter 5 compares the two models as to their relative advantages in answering the three aforementioned key questions in the thesis.

2 LEARNING AND COMMUNICATION IN ORGANISATION THEORY

This chapter reviews economic theory on organisations, focusing on aspects of learning, communication and the division of labour within organisations. It has been remarked that neoclassical economic theory has traditionally regarded organisations as black boxes, and therefore largely ignored the internal structure of organisations (see Hart 1989, 1757-1758; Stiglitz 1991). Particularly general equilibrium analysis views firm organisation as a production function, according to which inputs are turned into outputs. This view on firm organisation has, however, been accompanied with contributions of organisation theory and also of those of contract theory. (Böckerman 1996, 7.)

Among the first to attempt to explain the existence of firms in an economy was Ronald Coase. Coase's (1937) classic study examines why all transactions in an economy do not take place through the market mechanism. His recognition was that markets do not operate costlessly. Instead, there are costs to carrying out transactions, and these transaction costs differ depending on both the nature of the transaction and the way it is carried out. Therefore, the cost of using markets to form contracts is an explanation for the existence of firms: the higher is the cost of transacting across markets, the greater will be the comparative advantage of organising resources within the firm. (Coase 1937; Böckerman 1996, 7.)

Much research has later elaborated the idea of transaction costs, the most notable contributor being Oliver W. Williamson (see particularly Williamson (1975) and (1985)). Transaction cost theory can also be extended to the organisation of resources within a firm. In this context transaction costs are the costs of running a work system, that is, the costs of coordinating and motivating. Hence, an efficient organisation is determined by minimising transaction costs (Milgrom - Roberts 1992, 29).

In fact, transaction costs have been named as a limitation for labour specialisation. If a more extensive division of labour improves efficiency, what are the limits to specialisation within a firm? The reasoning behind the benefits of labour specialisation has a long history. Every other discussion on labour specialisation seems to begin with a reference to Adam Smith's writings on the gains from the division of labour. His basic idea was that gains from specialisation arise from the repetition of a task, which improves labour productivity in that task and avoids the fixed set-up costs incurred when labour switches between tasks[5].

Especially Arrow (1962) has later formalised the advantages of specialisation through the concept of learning-by-doing. Learning-by-doing, to put it simply, means that the productivity of a worker at a particular task increases with his experience in that task[6]. Therefore, a more extensive division of labour raises productivity[7]. However, with advanced labour specialisation, the problem of organisation arises as the actions of specialised workers need to be coordinated to achieve gains from cooperation (Becker - Murphy 1992). This means

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5 Therefore gains from specialisation exist without making difference to the different skill endowments of individuals. Specialisation has also been modelled from a slightly different point-of-view. In what has been referred to as the Ricardian approach, the benefits of specialisation are due to the utilisation of exogenous comparative advantages (see, e.g. Rosen 1978).

6 Learning-by-doing will be examined more thoroughly in chapters 3 and 4.

7 Consequently, learning-by-doing is often recognised as a source of long-term growth (see Lucas 1993).

that the analysis of the efficient organisational form has to take into account both the aspects of coordination and of labour specialisation. If the interactions of specialised workers are considered as transaction costs, the problem of organisation is reduced into minimising these transaction costs. Therefore, an optimal organisational structure maximises gains from specialisation while minimising transaction costs.

The formal analysis of coordination issues can be elaborated by the concept of information asymmetries. When firm organisation is seen as coordinating economic activity, where information has to be processed and shared in order to make decisions concerning production, two kinds of information asymmetry problems can be discerned (Leppämäki 2001). First, there are agency problems, which stem from the separation of ownership and control. In fact, agency theory has become a prominent branch of organisation theory, discussing information asymmetries between different agents in the economy. Much of the recent economic analysis on organisational design has concentrated on issues relating to individual incentives (for a survey, see Holmstrom - Tirole (1989)). For example, Holmstrom and Milgrom (1991) and Itoh (1994) have analysed optimal job designs and incentive structures under information asymmetries. They examine how the choice of the optimal combination of multiple tasks depends on the remuneration system and the measurability of task performance. The agency problem aspects are, however, beyond the scope of this study.

The second information asymmetry problem concerns information flows and communication costs, that is, the "technical" problems of information processing and communication (Leppämäki 2001). In a firm the information required to determine the best use of resources is most likely not freely available to everyone, as information may be dispersed and localised. The bounds on individuals' capabilities for information processing and decision making (i.e. bounded rationality[8]) ensure that no single individual can process all relevant information (Radner 1992). Therefore, information processing has to be organised among workers and information has to be communicated to the relevant decision-makers accordingly.

The literature often opposes two modes of decision-making: decentralisation and centralisation[9]. The problem of organisation arises from the fact that in complex organisations, both decentralisation and centralisation of decision-making contain costs. Crucial information lies with individuals, so centralising all aspects of decision-making requires that all this local information is communicated upward to the central decision makers, or else be ignored. Both are costly. But if all decisions are left to the individuals who actually take the actions, these decisions may be uncoordinated. Therefore, information processing and communication are costly activities, which are to be organised efficiently. The efficient organisational structure in terms of decision-making is an outcome of a trade-off determined by information processing and communication costs. (Milgrom - Roberts 1992, 113-114.)

Becker and Murphy (1992) find also that an important limitation for the degree of specialisation is the cost of combining specialised workers, who perform complementary tasks.

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8 Bounded rationality means that the limitations on human mental abilities that prevent people from foreseeing all possible contingencies and calculating their optimal behaviour. Bounded rationality may also include those limitations on human language that prevent perfect communication of those things that are known. (Milgrom - Roberts 1992, 596.)

9 A particular decision is decentralised if it is left to individuals alone to make. A decentralised decision is on that is made at a higher level and communicated to the individuals.

From this standpoint organisations exist, to a large extent, to solve coordination problems in the presence of specialisation. Therefore, coordinating different pieces of knowledge, deciding who learns what, and how information should be shared are central issues with which an organisation must deal.

Becker and Murphy (1992) and also Bolton and Dewatripont (1994) base their analysis of efficient organisational structures on the trade-off between specialisation and communication costs[10]. According to Becker and Murphy (1992) the coordination of specialised workers is costly because of a set of problems such as principal-agent conflicts, hold-up problems and communication difficulties. In addition, coordination costs increase as the labour force grows and specialisation increases. Their analysis shows that specialisation increases until the higher productivity from a greater division of labour is just balanced by the greater costs of coordinating a larger number of specialised workers. (Becker - Murphy 1992.)

Bolton and Dewatripont (1994) build on the approach of Becker and Murphy (1992). They see the firm organisation as a ”communication network” that is designed to minimise both the costs of processing new information and the costs of communicating information among its agents. Communication is costly because information processing is necessarily time-consuming. However, there are returns to specialisation in processing information when agents specialise in the handling of different types of information. A centralised organisation minimises communication costs, because centralisation avoids unnecessary duplication in communication. Hence, the efficient communication networks take the hierarchical form. (Bolton - Dewatripont 1994.)

In line with the analysis of Becker and Murphy (1992), the central feature of the analysis of Bolton and Dewatripont is that the trade-off between specialisation and communication determines the efficient form of the network. When more agents are added into the network and each agent handles more specialised information, the returns to specialisation grow. These returns are, however, partly offset by the increased costs of communication within the enlarged group of agents. Communication costs increase when specialisation grows because ever more communication is necessary to coordinate all these agents’ activities. (Bolton - Dewatripont 1994.)

An interesting result in the model of Bolton and Dewatripont is that a reduction in communication costs (e.g. improvements in information technologies) leads to the flattening of hierarchical structures. Moreover, improvements in these technologies may lower the costs of acquiring knowledge. Bolton and Dewatripont (1994) and Becker and Murphy (1993) view information processing primarily in terms of information sharing with exogenous information flows. However, although this thesis examines how communication costs limit the extent of specialisation, it also considers the accumulation of knowledge through learning-by-doing.

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10 Hart and Moore (1999) have also developed a model of hierarchies based on the allocation of authority. Their approach comes close to that of this thesis in that they view the optimal chain of command given that different agents have different tasks: some agents are engaged in coordination and others in specialisation. Their approach on organisational forms is, however, rather from the point of view of control and individuals’ utility, and not from the point of view of organisational information processing and knowledge creation. A complementary view focuses on what kind of an organisation makes the best decisions. Sah and Stiglitz (1986) examine how the organisational form affects the quality of decision-making, when individuals’ judgments unavoidably contain errors. They argue that the way people are arranged in an organisation affects the way errors are made in that organisation.

The study of Aoki (1986) addresses also knowledge acquisition, that is, learning. Specifically, he examines organisations, whose aim is to structure the acquisition of knowledge so as to economise learning and communication costs. A firm will be more or less efficient depending on the way it is organised, because the organisation determines the costs and results of collective information processing.

Aoki compared two modes of coordination, a "hierarchical" and a "horizontal" one. The efficiency of the hierarchical organisation is attained through worker specialisation and rational hierarchical control, in which instructions for workers are made beforehand. In the horizontal organisation, on the other hand, workers' jobs are not specified in detail. Hence, while performing many tasks workers gradually learn by doing and become familiar with the whole work process. In this type of an organisation efficiency is derived from workers' "grass roots" capability to cope with unforeseen events, facilitated by collective learning-by-doing, which by definition does not require a priori knowledge. Shop floor information is therefore better used, as workers can themselves react directly to unexpected events. For instance, if a breakdown of machinery or worker absenteeism occurs, the workers can themselves react to the problem. In the centralised organisation, by contrast, workers are not responsible of coping with unforeseen events. Instead, they are handled by supervisors or engineers. Therefore, the need for costly vertical information flow is reduced in the horizontal organisation compared to the hierarchical coordination style. (Aoki 1986.)

Aoki found that a decentralised organisation is more efficient than the centralised one if the possible disruptions in production are continuous and relatively small, and if the workers' skill levels are sufficiently high and their skills improve sufficiently fast through learning-by-doing. On the other hand, the traditional centralised organisation is more efficient when the organisation faces large changes and disruptions in production. The shortcoming of the decentralised organisation is that it may not be sufficiently prepared for large changes in the economy. (Aoki 1986.)

Aoki's analysis comes closest to the analysis in this thesis in that it determines the optimal organisational form by addressing both learning-by-doing and the sharing of information within an organisation, as in the Greenan - Guellec model in chapter 4. The following analysis will address explicitly the creation of information, that is, learning in an organisation. In Aoki's model the crucial factor determining the relative efficiency of the two coordination styles is uncertainty; whereas in the Greenan - Guellec model it will be product differentiation. Greenan and Guellec point out, however, that these are not in fact that far from each other, as product differentiation necessarily brings about uncertainty. (Aoki 1986; Greenan - Guellec 1994.)

Next, however, learning and the optimal degree of labour specialisation are examined on the basis of the model of Lindbeck and Snower (2000). The model leaves aside problems concerning communication, so in this sense it takes a step back in the discussion above. Nonetheless, this simplification allows the model to concentrate on the analysis of labour specialisation on the worker level by including another mechanism of learning besides learning-by-doing. The model asserts that learning-by-doing is behind the returns to specialisation, just as discussed above. Changes in technology or workers' human capital may, however, increase the returns to learning across tasks, that is, in favour of less specialisation. Therefore, whereas coordination costs were in the above named as a limit to labour specialisation, the Lindbeck - Snower model implies that also learning across tasks may limit the relative returns to specialisation. (Lindbeck - Snower 2000.)

3 LABOUR SPECIALISATION WITHIN FIRMS

Lindbeck and Snower (2000) depict in their model the reorganisation process of work within firms in advanced market economies. They argue that developments in production and information technologies have had the effect that initially traditional industrial firms have found it profitable to change their organisations. The movement has been from the hierarchical mass production model to a flatter organisation, where control and decision-making have been decentralised, teamwork and job rotation increasingly used, and continuous learning emphasised. The authors call the latter organisation type "holistic", whereas the traditional mass production model is named "Tayloristic". Tayloristic organisations are labelled by strong specialisation by task. Labour, like capital is treated like a single-purpose input. In holistic organisations, on the other hand, labour is used in a more flexible and versatile way and work is characterised by integration of tasks, job rotation and learning across tasks. (Lindbeck - Snower 2000.)

Advances in production technologies and the changing nature of physical and human capital may have made holistic firms more efficient than traditional Tayloristic ones. The source of inefficiency is found in the complementarities between tasks performed by employees. The authors suggest that when many tasks are complementary to each other, workers should perform multiple tasks instead of specialising in one task. (Lindbeck - Snower 2001.)

According to Lindbeck and Snower the reorganisation process is lead by four inter-related driving forces. They are the increased use of information and communication technologies, advances in production technologies, growth in human capital, and the increasingly versatile work preferences of workers. The diffusion of information and communication technologies has made it easier for workers to communicate with each other and provided workers greater access to information about other workers' jobs within an organisation. Decentralisation of decision-making is thereby facilitated, and workers can be more involved in each other's tasks.

The introduction of programmable and flexible production equipment contributes to the versatility of physical capital. Switching between the production of different products becomes easier and cheaper, permitting quicker production cycles and faster reaction to changing demands. Moreover, workers are then required to become more versatile, too. This is ensured by the continuing growth in human capital produced by extensive education systems. The authors argue that growth in human capital takes not only the form of "capital deepening", but also "capital widening", that is, the increased ability to acquire a variety of skills. Finally, workers' preferences about work have also changed towards varied work, which is largely a result of better education and more varied skills[11]. (Lindbeck - Snower 2000.)

As a result, a process of reorganisation of work within firms has been set on, whereby occupational barriers are breaking down. Although the process varies from firm to firm, Lindbeck and Snower name a few central features in the reorganisation process: increased use of teamwork and job rotation, flattening of organisations, continuous learning of new

11 Many studies have emphasised changes in demand side factors as the critical driving force of the reorganisation of production. Consumer preferences have become more varying and diverse, and to meet these demands production has to be reorganised. (Böckerman 1996, 45-46.)

skills and development of complementary skills, decentralisation of authority, and greater worker participation in decision-making. What all these have in common is emphasis on multitask learning, blurring of occupational boundaries and utilisation of experience gained in one task on another task. These are the very aspects covered in their model of work reorganisation. Particularly significant is the change in the role of learning and the returns to it in the new organisational environment. (Lindbeck - Snower 2000.)

This chapter is organised as follows. The model is presented in section 3.1. The premises of the model are first introduced in sections 3.1.1 and 3.1.2, and the firm's profit maximisation problem is examined in section 3.1.3. Section 3.2 examines the reorganisation process, whereby Tayloristic firms gain an incentive to adopt a holistic organisation. Finally, section 3.3 summarises the main findings of the model. Unless otherwise mentioned, the rest of the discussion in this chapter draws from Lindbeck and Snower (2000).

3.1 A model of the optimal degree of labour specialisation

The Lindbeck - Snower model aims to establish a relationship between the firm's organisational structure, namely, the degree of labour specialisation, and the firm's efficiency. It focuses on the allocation of tasks to workers, the feature the authors consider crucial in the reorganisation process. It is noteworthy that this is a question of intrapersonal allocation of tasks instead of interpersonal allocation of tasks. The questions to which this chapter aims to provide answers for are: why and with what conditions is a holistic organisation more efficient than a Tayloristic organisation, what the reasons for the reorganisation process are, and how they change the optimal organisational form. The consideration is done in a profit-maximising context.

3.1.1 Returns to specialisation vs. returns to task complementarities

When a firm decides whether its workers should specialise by task or perform multiple tasks, it faces a trade-off between two types of returns to worker productivity: (i) returns to specialisation and (ii) returns to task complementarities. Returns to specialisation come from "learning-by-doing" in the sense of Arrow (1962): a worker's productivity at a task increases with experience in that task. This is a result of *intratask* learning. Returns to task complementarities mean that a worker's productivity at one task increases with his experience at another task. Task complementarities can be further divided into technological and informational task complementarities.

Technological task complementarities are embedded in the positive cross-partial derivatives between different types of labour services in the production function. This means that different occupational types may be complementary. For example, the maintenance of machinery increases the productivity of workers using that machinery, or, the services of secretaries increase the productivity of managers. Informational task complementarities are a result of *intertask* learning, whereby the skills and information a worker acquires at one task raise his productivity at another task. Intuitively this sounds plausible, for example, when information gained at one end of the production line can be of use to a in the opposite end of the production line. One could name various examples; information gained in customer services can be of use in product design or marketing, information gained in production can be useful in quality control etc.

In other words, there is continuous learning in the model, which works through two mechanisms: intratask and intertask learning. Both learning mechanisms improve employee productivity, which is expressed by different types of returns to productivity. In reality the results of learning are shown only with the course of time. To simplify things, the model covers, however, only one period, and therefore the length of this period should be considered as long enough for these returns to become evident.

3.1.2 The setup of the model

In the model there is a firm, which produces output q by performing two tasks (1,2)[12]. The firm's employees can be divided into two homogeneous groups: type-1 workers and type-2 workers, who differ in terms of their comparative advantage at the two tasks. Therefore, the approach to specialisation of labour incorporates also the Ricardian view, whereby the benefits of specialisation are due to the utilisation of exogenous comparative advantages (Borland -Yang 1992). Type-1 workers have a comparative advantage in performing task 1, and type-2 workers have a comparative advantage in performing task 2. The comparative advantage of either employee type is given according to their skills.

The authors represent the returns to specialisation and the returns to informational complementarities as separate variables. They admit that it might not be possible to identify the two types of returns in practice, but it is useful in the modelling of the learning process. The type-1 worker's return to specialisation on either task depends positively on the fraction of time he spends on that task. Let τ, $(0 \le \tau \le 1)$, denote the fraction of time the worker spends on task 1, whereas fraction $(1-\tau)$ is spent on task 2[13]. The type-1 worker's return to specialisation $(s_i,\ i=1,2)$ is $s_1 = s_1(\tau)$ at task 1, and $s_2 = s_2(1-\tau)$ at task 2, where $s_1', s_2' > 0$.

The return to informational task complementarity is expressed in the model by letting the worker's productivity in one task depend on his experience at another task. The greater the fraction of time a worker devotes to task *i,* the more information he gains about this task and the more productive he becomes in task $j,\ j \ne i$. The return to informational task complementarity is denoted by $c_{1,2}$: $c_1 = c_1(1-\tau)$ and $c_2 = c_2(\tau)$ at task 1 and 2 respectively, where $c_1', c_2' > 0$. Specifically, c_1 is the worker's ability to increase his productivity at task 1 through time $(1-\tau)$ spent on task 2. Similarly, c_2 is his ability to increase his productivity at task 2 through time spent (τ) on task 1.

Returns to specialisation and to informational task complementarities determine the type-1 worker's productivity. The authors express this by "efficiency units of labour" e_1 and e_2 for type-1 workers per hour in tasks 1 and 2, respectively. Type-1 worker's efficiency units

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12 Physical capital is fixed during the period.
13 Each worker's available working time is normalised to unity.

are made up of the sum of returns to specialisation and returns to informational task complementarities:

$$e_1 = s_1(\tau) + c_1(1-\tau) = e_1(\tau), \qquad (1a)$$
$$e_2 = s_2(1-\tau) + c_2(\tau) = e_2(\tau),$$

where $(\partial e_i / \partial s_i) > 0$ and $(\partial e_i / \partial c_i) > 0,\ i = 1,2$ (Lindbeck - Snower 2001). In short, a worker's efficiency on one task depends on the time devoted to that task and time devoted to the other task.

This logic applies similarly to the type-2 worker[14]. Type-2 worker's return to specialisation $(S_i,\ i = 1,2)$ at each task depends positively on the fraction T of time devoted to that task: $S_1 = S_1(1-T)$ and $S_2 = S_2(T)$, $S_1{}', S_2{}' > 0$. The return to informational task complementarity depends on the time devoted to the other task: $C_1 = C_1(T)$ and $C_2 = C_2(1-T)$, where $C_1', C_2' \geq 0$. Again the efficiency units of labour for the type-2 worker in each task, E_1 and E_2, are expressed as the sum of the returns to specialisation and the returns to informational task complementarities:

$$E_1 = S_1(1-T) + C_1(T) = E_1(T), \qquad (1b)$$
$$E_2 = S_2(T) + C_2(1-T) = E_2(T),$$

where $(\partial E_i / \partial S_i) > 0$ and $(\partial E_i / \partial C_i) > 0,\ i = 1,2$ (Lindbeck - Snower 2001).

To sum up, time allocations τ and T generate human capital in type-1 and type-2 workers, respectively. This human capital contributes to workers' efficiency units of labour through returns to specialisation and returns to informational task complementarities. Another way to think of the allocations of τ and T is that they define the degree of worker specialisation and hence the firm's organisation of work.

In a firm there are a number of n type-1 workers and a number of N type-2 workers. Then the total labour services in efficiency units devoted to task 1 (λ_1) and to task 2 (λ_2) are:

$$\lambda_1 = e_1(\tau) \times \tau \times n + E_1(1-T) \times (1-T) \times N = \Lambda_1(\tau, T; n, N), \qquad (2)$$
$$\lambda_2 = e_2(1-\tau) \times (1-\tau) \times n + E_2(T) \times T \times N = \Lambda_2(\tau, T; n, N).$$

As can be seen in the equations above, changes in the time allocation between the two tasks have three kinds of effects on labour services. Say that (τ) increases, that is, a type-1 worker increases the time spent on task 1. First, this has a direct, positive effect on type-1 labour services (λ_1) through increased labour time. Second, there is a positive effect through increased returns to specialisation. Finally, there is a negative effect through de-

[14] Type-1 worker's variables denoted in lower case and type-2 worker's variables in upper case.

creased returns to informational complementarities. The effects are analogous for type-2 workers.

The firm's production function is:

$$q = f(\Lambda_1(\tau, T; n, N), \Lambda_2(\tau, T; n, N)), \tag{3}$$

where q is the firm's output, $f_i > 0$, $f_{ii} < 0$ $(i = 1,2)$, and $f_{ij} > 0$ $(i = 1,2$ and $j \neq i)$. $f_i > 0$ means that increasing labour services devoted to either task increases production whereas $f_{ii} < 0$ stands for diminishing returns to labour. Here the technological task complementarities are expressed by the positive cross-partial derivatives f_{ij} $(i = 1,2$ and $j \neq i)$. This means that increasing labour services in task *j* increases the marginal product of labour at task *i*.

Since labour is the only input, wage costs are the only costs incurred to the firm. When ω and W are the real wages for type-1 and type-2 workers respectively, the firm's real labour costs are $\omega n + WN$. The wages are assumed to be the reservation wages of these workers, that is, the wages with which workers are indifferent between employment in that firm or employment somewhere else. Workers are assumed to have preferences about the organisation of work. If workers prefer specialised to versatile work, then their reservation wage achieves a maximum at $\tau = 1/2$, when they devote equal amounts of time to both tasks. If workers prefer versatile work, their reservation wage attains a minimum at $\tau = 1/2$. Therefore, provided that the wage depends positively on the reservation wage, it is specified that $\omega = \omega(\tau)$, $\omega'(1/2) = 0$; and if the workers prefer specialisation, then $\omega'' < 0$, whereas if they prefer versatility, then $\omega'' > 0$.

The firm's profit is:

$$\pi(\tau, T; n, N) = f(\Lambda_1(\tau, T; n, N), \Lambda_2(\tau, T; n, N)) - \omega(\tau)n - W(T)N, \tag{4}$$

where the price of output has been normalised to one.

The comparative advantage of type-1 workers is shown in the following assumption:

$$\pi(1, T; n, N) > \pi(0, T; n, N), \tag{5a}$$

for any T, $0 \leq T \leq 1$. This can be rewritten as:

$$f(\Lambda_1(1, T; n, N), \Lambda_2(1, T; n, N)) - \omega(1)n - W(T)N$$
$$> f(\Lambda_1(0, T; n, N), \Lambda_2(0, T; n, N)) - \omega(0)n - W(T)N,$$

for any T, $0 \leq T \leq 1$. Thereby regardless of how time is allocated between the two tasks for type-2 workers, it is always more profitable for the type-1 worker to devote all his time to task 1 than to devote all his time to task 2. The same applies for type-2 workers:

$$\pi(\tau,1;n,N) > \pi(\tau,1;n,N), \tag{5b}$$

for any T, $0 \le T \le 1$. Again, this can be rewritten as:

$$\begin{aligned} & f(\Lambda_1(\tau,1;n,N),\Lambda_2(\tau,1;n,N)) - \omega(\tau)n - W(1)N \\ & > f(\Lambda_1(\tau,0;n,N),\Lambda_2(\tau,T;0,N)) - \omega(\tau)n - W(0)N, \end{aligned}$$

for any τ, $0 \le \tau \le 1$.

The two groups of workers are in analogous positions in the firm's production function and they incur analogous costs to the firm. Therefore the analysis from here on focuses only on the type-1 worker.

3.1.3 The firm's profit maximisation problem

The firm maximises its profits with respect to the number of workers (*n* and *N*) and the workers' time allocation to tasks (τ and *T*). In a Tayloristic organisation of work, type-1 workers specialise according to their comparative advantage in task 1, whereas type-2 workers specialise in task 2, so that $\tau^* = 1$ and $T^* = 1$[15]. In a holistic work organisation, workers perform both tasks, so that $0 < \tau^* < 1$. Proposition 1 shows how the profit maximising firm chooses its organisation of work:

PROPOSITION 1.

Given the profit function $\pi = \pi(\tau,T;n,N)$, the necessary conditions for a holistic organisation of work is that there exists a time allocation τ^* in the interval $0 < \tau^* < 1$, such that

$$\left.\frac{\partial \pi}{\partial \tau}\right|_{\tau=\tau^*} = 0,$$

and

$$\left.\frac{\partial^2 \pi}{\partial \tau^2}\right|_{\tau=\tau^*} < 0.$$

When $\tau^* = 1$ the condition is violated and the organisation of work is Tayloristic. In a Tayloristic organisation workers specialise by task and therefore the profit-maximising allocation of time across tasks lies at a corner point. In a holistic organisation workers perform both tasks, so the profit maximising allocation of time must lie in an interior point of the feasible set $0 \le \tau \le 1$.

The factors influencing the firm's choice of organisational form are examined next. The marginal profit from a change in the organisation of work with respect to the time allocation τ is:

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[15] In a profit maximising point τ^* (or T^*) is never zero, because workers specialise according to their comparative advantages.

$$\frac{\partial \pi}{\partial \tau} = f_1 \frac{\partial \Lambda_1}{\partial \tau} + f_2 \frac{\partial \Lambda_2}{\partial \tau} - \frac{\mathrm{d}\omega}{\mathrm{d}\tau} n,$$

which can be expressed as:

$$\frac{\partial \pi}{\partial \tau} = \mathrm{MR} - \mathrm{MC}^{\mathrm{o}} - \mathrm{MC}^{\mathrm{w}}, \tag{6}$$

where $\mathrm{MR} = f_1 \partial\Lambda_1 / \partial\tau$, $\mathrm{MC}^{\mathrm{o}} = -f_2(\partial\Lambda_2 / \partial\tau)$ and $\mathrm{MC}^{\mathrm{w}} = (\mathrm{d}\omega/\mathrm{d}\tau)n$. Therefore, there are three elements affecting marginal profit with respect to time allocation τ. MR is the marginal revenue with respect to τ. Increasing the fraction τ of time devoted to task 1 changes the firm's revenue by changing the labour services devoted to task 1. MC^{o} is the marginal opportunity cost of task 1 in terms of task 2. An increase in the fraction τ of time changes the revenue by changing the labour services devoted to task 2. MC^{w} is the marginal cost due to changes in the wage rate, which result from changes in the time allocation τ. Hence, compared to the textbook case with marginal revenues and marginal costs derived from different elements in the profit-maximising function (production function and cost function), the marginal opportunity cost MC^{o} is derived from the production function. The marginal revenue and marginal cost terms are illustrated in figure 3.1.

The change in the marginal profit with respect to time allocation τ is:

$$\frac{\partial^2 \pi}{\partial \tau^2} = \frac{\partial \mathrm{MR}}{\partial \tau} - \frac{\partial \mathrm{MC}^{\mathrm{o}}}{\partial \tau} - \frac{\partial \mathrm{MC}^{\mathrm{w}}}{\partial \tau}, \tag{7}$$

where

$$\frac{\partial \mathrm{MR}}{\partial \tau} = \left[\left(f_{11} \frac{\partial \Lambda_1}{\partial \tau} + f_{12} \frac{\partial \Lambda_2}{\partial \tau} \right) \frac{\partial \Lambda_1}{\partial \tau} + f_1 \frac{\partial^2 \Lambda_1}{\partial \tau^2} \right], \tag{8}$$

$$\frac{\partial \mathrm{MC}^{\mathrm{o}}}{\partial \tau} = -\left[\left(f_{21} \frac{\partial \Lambda_1}{\partial \tau} + f_{22} \frac{\partial \Lambda_2}{\partial \tau} \right) \frac{\partial \Lambda_2}{\partial \tau} + f_2 \frac{\partial^2 \Lambda_2}{\partial \tau^2} \right], \tag{9}$$

$$\frac{\partial \mathrm{MC}^{w}}{\partial \tau} = \frac{\mathrm{d}^2 \omega}{\mathrm{d}\tau^2} n. \tag{10}$$

It is assumed that the tasks are technological complements and the cross-partial derivatives are positive: $f_{12} = f_{21} > 0$. In other words, increasing labour services on one task increases the marginal returns to labour services on the other task. Moreover, as $(\partial\Lambda_1 / \partial\tau) > 0$, $(\partial\Lambda_2 / \partial\tau) < 0$ and $f_{11} < 0$, the first term of equation (8) is negative[16]. Since $f_1 > 0$, the sign of the derivative of MR depends on the sign of $(\partial^2\Lambda_1 / \partial\tau^2)$, which measures the diminishing (or increasing) labour services returns to the time allocation τ.

16 $(\partial\Lambda_1 / \partial\tau) > 0$ and $(\partial\Lambda_2 / \partial\tau) < 0$ mean that increasing time allocation to task 1 (increasing τ) increases total labour services to task 1 and decreases total labour services to task 2, which is evident.

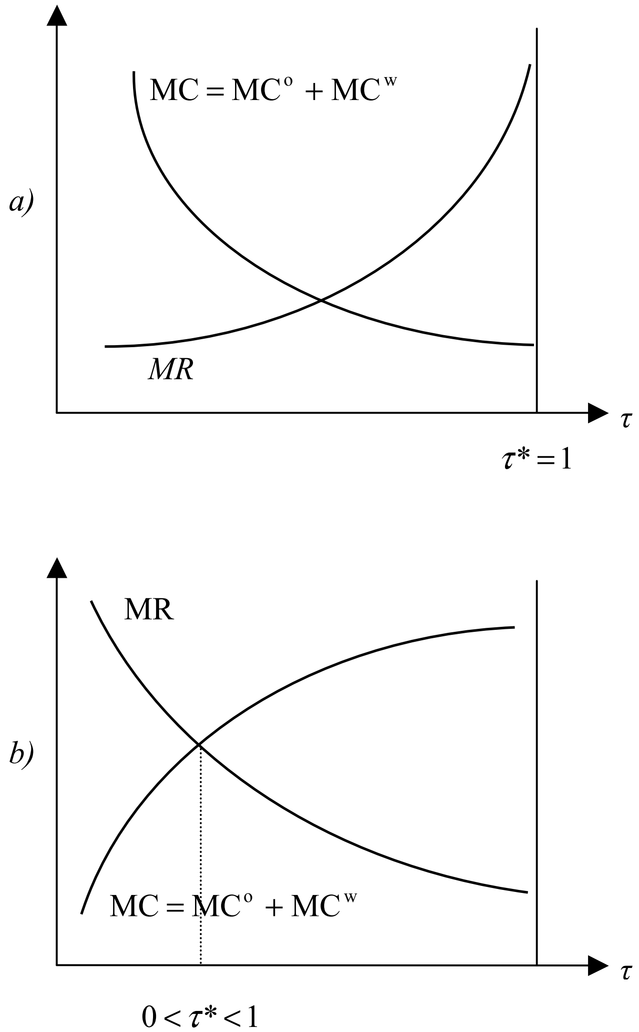

Figure 3.1. The organisation of work: a) Tayloristic organisation, b) holistic organisation.

The term $(\partial^2\Lambda_1/\partial\tau^2)$ depends on the return to specialisation relative to the return to informational task complementarity. As τ rises from zero to unity, the type-1 worker's return to specialisation at task 1 rises, but the return to the informational task complementarity falls (i.e. productivity in task 1 gained from information at task 2). The faster the rate at which the return to the informational task complementarity falls relative to the rate at which the return to specialisation rises as τ rises, the more slowly the labour services devoted to task 1 rise as τ rises and the lower is $(\partial^2\Lambda_1/\partial\tau^2)$. Therefore, the more rapidly the marginal revenue falls (or the more slowly it rises) with respect to τ. The more rapidly the marginal revenue falls, the more worthwhile it eventually becomes to adopt a holistic organisation of work. This result can be seen in parts *a* and *b* of figure 3.1.

The expression for the change of marginal opportunity cost of task 1 in terms of task 2 with respect to a change in the time allocation τ was:

$$\frac{\partial \mathrm{MC^o}}{\partial \tau} = -\left[\left(f_{21}\frac{\partial \Lambda_1}{\partial \tau} + f_{22}\frac{\partial \Lambda_2}{\partial \tau}\right)\frac{\partial \Lambda_2}{\partial \tau} + f_2\frac{\partial^2 \Lambda_2}{\partial \tau^2}\right]. \tag{9}$$

The first term is positive, because $(\partial\Lambda_1/\partial\tau) > 0$, $(\partial\Lambda_2/\partial\tau) < 0$, $f_{22} < 0$ and $f_{21} > 0$. Again the sign of equation (9) depends on the last term. Since f_2 is positive, $(\partial^2\Lambda_2/\partial\tau^2)$, the diminishing or increasing returns to time allocation τ, determines the sign of behaviour of the marginal opportunity cost.

The line of thought is here similar as above, but the other way around. As τ rises from zero to unity, the type-1 worker's return to specialisation at task 2 falls, but the return to informational task complementarity rises (i.e. increase in productivity in task 2 gained from information at task 1). The faster the rate at which the return to specialisation at task 2 falls relative to the rise in return to informational task complementarity at task 2 as τ rises, the lower is $(\partial^2\Lambda_2/\partial\tau^2)$. Therefore, the greater is $(\partial \mathrm{MC^o}/\partial\tau)$, which means that the faster will the marginal opportunity cost MC^o rise (or the more slowly will it fall) with respect to τ. Consequently, as illustrated in figure 3.1, the firm eventually gains an incentive to adopt a holistic organisation.

The change in marginal cost in terms of the wage with respect to time allocation τ was:

$$\frac{\partial \mathrm{MC}^w}{\partial \tau} = \frac{\mathrm{d}^2\omega}{\mathrm{d}\tau^2} n. \tag{10}$$

Since n is naturally positive, the sign of equation (10) depends on $(\mathrm{d}^2\omega/\mathrm{d}\tau^2)$, the workers' preferences regarding the versatility of work. If type-1 workers have versatile preferences, then as τ approaches unity, the wage cost of these workers eventually rises. The more the workers prefer versatile to specialised work, the greater is $(\mathrm{d}^2\omega/\mathrm{d}\tau^2)$ and the reservation wage attains a minimum at $0 < \tau < 1$. The greater is $(\mathrm{d}^2\omega/\mathrm{d}\tau^2)$, the faster will the reservation wage rise with τ and the faster will marginal cost rise (or the more slowly it will fall) with respect to τ. Again, it becomes more attractive for the firm to eventually adopt a holistic organisation, as figure 3.1 implies.

In part *a* of figure 3.1, it is assumed that (i) the return to specialisation increases fast enough relative to the return to informational complementarity, and (ii) the type-1 workers have strong enough preferences for specialised work. Therefore marginal revenue rises with τ, i.e. $(\partial \mathrm{MR}/\partial\tau > 0)$, and the total marginal cost $(\mathrm{MC} = \mathrm{MC^o} + \mathrm{MC^w})$ declines with τ, i.e. $(\partial \mathrm{MC}/\partial\tau < 0)$. Therefore, the firm's organisation of work is Tayloristic. This kind of a situation would fit into the classic pin factory example with workers who prefer specialised, monotonic work. Taken that the design of pins remains fairly constant and the similarly stabile technology favours specialisation, high returns to specialisation are expected as workers become increasingly productive in their narrow tasks through learning-by-doing.

In part *b* of figure 3.1, it is assumed that (i) the return to informational task complementarity increases fast enough relative to the returns to specialisation, and (ii) the type-1 workers have strong enough preferences for versatile work. Therefore marginal revenue falls with τ

and total marginal cost rises with τ. The marginal cost and marginal revenue curves intersect at $\tau^* < 1$ and the firm's organisation of work is holistic.

In the same pin factory example as above, imagine a totally computerised pin production system with highly educated workers who prefer versatile work. There may be high task complementarities between, say, sales and production tasks. When the worker who performs both sales and production tasks receives a pin order, he can immediately program the needed production. If the sales tasks were performed by another worker, time would go by before the order would be communicated to the production worker. Hence, this is an very simple example of high returns to task complementarities compared to low returns to specialisation in a holistic organisation.

In sum, under these assumptions there are two factors determining the organisational structure of a firm. First, the relationship between the returns to specialisation and the returns to informational task complementarities determine the marginal revenue and marginal opportunity cost of one task in terms of the other task. Second, worker preferences regarding the versatility of work determine marginal cost in terms of the wage. Finally, the optimal form of organisation can be determined from the behaviour of marginal revenue and marginal costs with respect to the time allocation between tasks.

3.2 The organisational restructuring process

The restructuring process, whereby an initially Tayloristic firm turns into a holistic organisation, is now examined. As mentioned earlier, the authors argue that the restructuring process results from four underlying forces: (1) changes in physical capital, (2) changes in information technology, (3) changes in workers' preferences, and (4) changes in human capital. These changes and their implications are now discussed more closely.

3.2.1 Physical capital

The discussion about physical capital centres on the technological task complementarities associated with physical capital, that is, whether physical capital provides opportunities to exploit technological task complementarities. Analytically, technological task complementarities are embedded in the positive cross-partial derivatives of the production function. According to Lindbeck and Snower only certain types of changes increase the scope for technological task complementarities and thereby increase incentives to restructure into a holistic organisation. Namely, those are the changes that affect the flexibility and versatility of physical capital across tasks.

The authors argue that whereas the major changes in physical capital occurring in the first half of the twentieth century favoured Tayloristic organisations, the more recent changes are strongly biased in favour of holistic organisations. The breakthroughs in mass production and mass marketing in the first half of the last century (e.g. assembly lines, specialised manufacturing equipment and hierarchical organisations) accentuated returns to scale at specialised tasks. In terms of this analysis, physical suited to specialised mass production was associated with large returns to specialisation by task and low technological task complementarities (i.e. low intertask cross-partial derivatives $f_{12} = f_{21}$).

Recently the advances in physical capital (e.g. programmable machinery, multipurpose tools) have made machinery more versatile across tasks. Consequently, it is easier for firms to take advantage of intertask complementarities. There could be, for instance, complementarities between production and sales tasks brought about by programmable machinery: if machinery can be easily reprogrammed to produce varying products, faster reaction to changing consumer demands is permitted and thereby it is easier to exploit complementarities between production and sales tasks. As the authors put it, “as machines have become more versatile, so, too, has labour been enabled to become more versatile” (ibid. 368).

The intuition becomes clearer if the concept of technological task complementarity is compared to the concept of technological task substitutability. In the previous section it was shown that when time allocation τ rises from zero to unity, the marginal product of labour at task 1 decreases. On the other hand, the existence of technological task complementarities ($f_{12} > 0$) means that the tasks are Edgeworth[17] complements in the production function. A rise in time allocation τ reduces the marginal product of task 1, but raises the marginal product of task 2. The greater the technological task complementarity relative to the rate of diminishing returns to labour, the greater the incentive to switch to a holistic organisation. Technological task substitutability (i.e. $f_{12} < 0$), on the other hand, reinforces the diminishing returns to labour and strengthens the incentive for a Tayloristic organisation.

The implications of an increase in the cross-partial derivatives $f_{12} = f_{21}$ can be distinguished in equation (7). An increase in the cross-partial derivatives reduces the value of $(\partial^2\pi / \partial\tau^2)$, the second derivative of the profit function with respect to τ. This happens through two mechanisms. First, there is a decrease in $(\partial \mathrm{MR} / \partial\tau)$, which means that marginal revenue falls more rapidly with respect to τ. Second, there is an increase in $(\partial \mathrm{MC}^{o} / \partial\tau)$, which means that the marginal opportunity cost of task 1 in terms of task 2 rises more rapidly with respect to τ.

Rewriting equation (7) we get:

$$\frac{\partial^2\pi}{\partial\tau^2} < 0 \Leftrightarrow f_{12} > \frac{1}{\dfrac{\partial\Lambda_1}{\partial\tau}\dfrac{\partial\Lambda_2}{\partial\tau}}\left[-f_{11}\left(\frac{\partial\Lambda_1}{\partial\tau}\right)^2 - f_1\frac{\partial^2\Lambda_1}{\partial\tau^2} - f_{22}\left(\frac{\partial\Lambda_2}{\partial\tau}\right)^2 - f_2\frac{\partial^2\Lambda_2}{\partial\tau^2} + \frac{d^2\omega}{d\tau^2}n\right]\frac{1}{2}.$$

Therefore, if a rise in f_{12} is large enough in order to lower the second derivative of the profit function sufficiently for the above inequality to hold, the firm may choose a holistic organisation of work.

[17] Edgeworth complements correspond to positive mixed partial derivatives of some payoff-function: the marginal returns to one variable are increasing in the levels of the other variables. (Milgrom - Roberts 1995.)

3.2.2 Information technologies

The authors argue that the increasingly widespread use of information technologies and especially the advances in these technologies have eased firms' possibilities to take advantage of informational task complementarities. The reason is that workers are provided fast and cheap access to information. Thereby information technologies encourage the exercise of multiple skills over multiple tasks and provide scope for intertask learning. As a result, the returns to informational complementarities have reinforced relative to the returns to specialisation.

In the model an increase in informational task complementarities can be represented as increases in $(\partial e_1 / \partial c_1)$ and $(\partial e_2 / \partial c_2)$, which indicate to increases in the rate at which the worker efficiency in one task rises as the return to informational complementarity from the other task rises. As equations (11a) and (11b) show, increases in $(\partial e_1 / \partial c_1)$ and $(\partial e_2 / \partial c_2)$ reduce $(\partial \Lambda_1 / \partial \tau)$ and $(\partial \Lambda_2 / \partial \tau)$:

$$\frac{\partial \Lambda_1}{\partial \tau} = \left(\frac{\partial e_1}{\partial s_1} - \frac{\partial e_1}{\partial c_1} \right) \tau n + e_1 n \tag{11a}$$

and

$$\frac{\partial \Lambda_2}{\partial \tau} = -\left(-\frac{\partial e_2}{\partial s_2} + \frac{\partial e_2}{\partial c_2} \right)(1-\tau)n - e_2 n. \tag{11b}$$

As a result, marginal revenue will fall more rapidly with respect to the time allocation τ and make the marginal opportunity cost of task 1 in terms of task 2 rise more rapidly with respect to τ. Therefore the value of $(\partial^2 \pi / \partial \tau^2)$ is reduced. As concluded before, if this value is negative, the firm may choose a holistic organisational form.

Furthermore, if we assume that $(\partial^2 \Lambda_1 / \partial \tau^2) = (\partial^2 \Lambda_2 / \partial \tau^2)$, then by equation (7) we get:

$$\frac{\partial^2 \pi}{\partial \tau^2} < 0 \Leftrightarrow \frac{\partial^2 \lambda_i}{\partial \tau^2} < \frac{1}{f_1 + f_2} \left[-\left(f_{11} \frac{\partial \Lambda_1}{\partial \tau} + f_{12} \frac{\partial \Lambda_2}{\partial \tau} \right) \frac{\partial \Lambda_1}{\partial \tau} - \left(f_{21} \frac{\partial \Lambda_1}{\partial \tau} + f_{22} \frac{\partial \Lambda_2}{\partial \tau} \right) \frac{\partial \Lambda_2}{\partial \tau} + \frac{\partial^2 \omega}{\partial \tau^2} n \right],$$

for $i = 1,2$. Consequently, a change in information technologies that reduces the value of $(\partial^2 \Lambda_i / \partial \tau^2)$ will reduce the second derivative of the profit function $(\partial^2 \pi / \partial \tau^2)$. If the change is large enough to satisfy the inequality above, the firm may choose a holistic work organisation.

3.2.3 Worker preferences

Finally, if worker preferences change towards more versatile work, the value of $(\partial^2 \omega / \partial \tau^2)$ increases. Thereby marginal cost $(\partial \mathrm{MC}^{\mathrm{w}} / \partial \tau)$ increases, which reduces

$(\partial^2\pi / \partial\tau^2)$. The authors refer to evidence from sociological and business literature, according to which many workers have a growing need to be stimulated at work. Holistic work tends to be more varied and creative than work in Tayloristic, narrowly defined jobs, and therefore workers are less willing to work in Tayloristic than in holistic organisations.

In the model this can be represented again by equation (7):

$$\frac{\partial^2\pi}{\partial\tau^2} < 0 \Leftrightarrow \frac{\partial^2\omega}{\partial\tau^2} > \frac{1}{n}\left[\left(f_{11}\frac{\partial\Lambda_1}{\partial\tau} + f_{12}\frac{\partial\Lambda_2}{\partial\tau}\right)\frac{\partial\Lambda_1}{\partial\tau} + f_1\frac{\partial^2\Lambda_1}{\partial\tau^2}\right]$$
$$+ \frac{1}{n}\left[\left(f_{21}\frac{\partial\Lambda_1}{\partial\tau} + f_{22}\frac{\partial\Lambda_2}{\partial\tau}\right)\frac{\partial\Lambda_1}{\partial\tau} + f_2\frac{\partial^2\Lambda_2}{\partial\tau^2}\right].$$

If $(\partial^2\omega / \partial\tau^2)$ is large enough so that $(\partial^2\pi / \partial\tau^2) < 0$, the firm may choose a holistic organisational form.

3.2.4 Human capital

The last aspect is the steady growth of human capital brought about by extensive education systems. The increase of human capital facilitates the adoption of holistic organisations. There are many aspects to human capital growth (productivity of labour, transferability of skills), but the focus is here specifically on the widening of human capital: the increased ability to perform multiple tasks.

The line of thought here differs somewhat from the previous discussion about the restructuring process. The implications of changes in physical capital, information technologies and worker preferences were to reduce $(\partial^2\pi / \partial\tau^2)$ and eventually make it negative. However, the negative value of $(\partial^2\pi / \partial\tau^2)$ is not enough to make a holistic organisation more profitable than a Tayloristic one. In addition, as the first-order condition in proposition 1 requires, it should be that $(\partial\pi / \partial\tau) = 0$ for $0 < \tau < 1$. The "widening" of human capital contributes to this aspect. If $(\partial^2\pi / \partial\tau^2) < 0$, then changes in human capital, which allow workers to do more versatile work, move the profit-maximising time allocation τ^* towards 1/2 (the interior of the feasible region $0 \leq \tau \leq 1$). Specifically, this favours a holistic work organisation by increasing the rate at which the marginal opportunity cost of task 1 in terms of task 2 rises with τ.

The profit-maximising organisational responses to the above-mentioned changes are summarised in proposition 2:

PROPOSITION 2.

In response to sufficiently large (1) changes in production technologies that increase the technological task complementarities, (2) changes in information technologies that increase the informational task complementarities, (3) changes in worker preferences in favour of versatile work, and (4) changes in human capital that increase worker versatility, Tayloristic organisations gain the incentive to restructure into holistic organisations.

These profit-maximising responses follow directly from the analytical discussion above. There are also implications for whether the restructuring process is continuous or discontinuous. Proposition 3 concerns the smoothness of the restructuring process:

PROPOSITION 3.

If the switch from a Tayloristic to a holistic organisation of work is brought about by human capital changes that make workers more versatile, then the restructuring process will be smooth. If, however, the switch is brought about by increases in technological task complementarities, increases in informational task complementarities or greater preferences for versatile work, then the restructuring process may be discontinuous.

Proposition 3 becomes evident by comparing the impacts of different changes. If it is the advances in information and production technologies that bring about the switch, then it is the change in the sign of $(\partial^2\pi/\partial\tau^2)$ that is responsible for the switch. Specifically, if $(\partial^2\pi/\partial\tau^2)>0$ in the original equilibrium, whereas $(\partial^2\pi/\partial\tau^2)<0$ and $(\partial\pi/\partial\tau)=0$ at $0<\tau<1$ in the new equilibrium, then the profit maximising allocation of hours changes discontinuously form complete specialisation to multitasking. This can be seen in part *a* in figure 3.2, where the initial profit function π_1 is maximised in at the Tayloristic point E_1, where $\pi^*=1$. When $(\partial^2\pi/\partial\tau^2)<0$, the maximum shifts discontinuously to $0<\tau^*<1$, as point E_2 in figure 3.2.

If, however, $(\partial^2\pi/\partial\tau^2)<0$ and the profit maximising time allocation is initially at $\pi^*=1$, then the changes in human capital that make workers more versatile will move the profit maximising time allocation gradually and continuously to the interior of the region $0\le\tau\le1$. This is illustrated in part *b* of figure 3.2. Initially the profit function achieves a maximum at the Tayloristic point E_a, where $\pi^*=1$. Changes in human capital gradually shift the profit function towards π_b and the maximum moves gradually towards E_b.

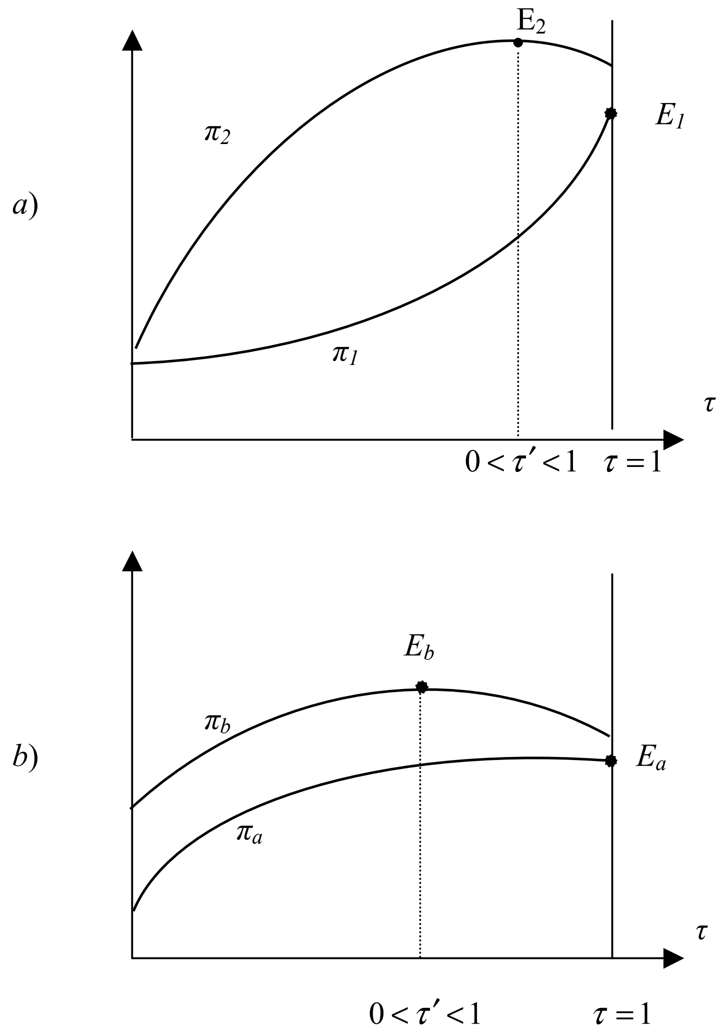

Figure 3.2: The restructuring process: *a*) The discontinuous process, *b*) The continuous process.

3.3 Findings

The Lindbeck - Snower model examined reorganisation of work within firms by focusing on the degree of labour specialisation. Two extreme cases were compared: a Tayloristic organisation, where workers are highly specialised by tasks; and a holistic organisation, where workers perform a variety of tasks. The analysis in a profit maximising context showed how and with what conditions an organisation based on multitasking can be more efficient compared to an organisation based on labour specialisation.

The relative efficiency of the two types of organisations was determined by the scope for intratask and intertask learning. Intratask learning is learning-by-doing in the sense of Arrow (1962): the more time a worker spends at a particular task, the more efficient he becomes in performing that task. Intertask learning, by contrast, arises when a worker can utilise the information and skills acquired at one task to improve his performance at another tasks. The returns to intratask and intertask learning determine the returns to specialisation and returns to task complementarities, respectively. If the returns to specialisation are high compared to the returns arising from the complementarities between tasks, it is more efficient to have a specialised Tayloristic work organisation. On the other hand, if the tasks are sufficiently complementary to each other, returns to task complementarities may outweigh the returns to specialisation. Consequently, the holistic organisation based on multi-tasking may be more efficient.

The tasks can be interpreted in a broad sense. They cover also the exercise of social and communication skills, initiative and creativity, and managerial skills such as judgement. Therefore the performance of multiple task may not only point to blurring of job boundaries between neighbouring occupations, but also between occupations traditionally held as separate, such as blue-collar and white-collar occupations.

The returns to intratask and intertask learning may vary because of various reasons. The opportunities for intertask learning can increase with the diffusion of information and communication technologies, which provide workers with easy and cheap access to information. Therefore, the returns to *informational task complementarities* increase.

In addition, the technology the firm uses has an effect on how tasks are technologically complementary to each other. In a holistic organisation technology is characterised by high *technological task complementarities*. Therefore, in a holistic organisation returns to task complementarities are sufficiently high compared to the returns to specialisation by task. Finally, the trend in workers' preferences regarding the versatility of work and the widening of human capital favour a holistic organisation. To put it in the language of the analysis above, the firm's optimal choice is a holistic organisation when there are rising costs and falling revenues associated with increasing task specialisation.

In reality we will hardly find either a "pure" Tayloristic or holistic organisation. The model points out, however, important developments. In practice an organisation may have both Tayloristic and holistic features. A production process may display different stages, where the optimal degree of labour specialisation varies. For example, teamwork can be used when a product development process in being initiated, when expertise is combined from several areas. During this "brainstorming" phase informational complementarities between occupations are utilised. In another stages workers may then retire to the tasks they are specialised in. These tasks may require a high degree of expertise in a narrow area, whereby there are increasing returns to specialisation.

Although the labour market implications of organisational change are beyond the scope of this study, the implications of organisational change for labour demand should not be ignored. One of the crucial assumptions made in the Lindbeck - Snower model was that firms face an endless supply of homogeneous labour. In reality, as skill levels vary among workers, the availability of skilled labour can be a considerable constraint to the firm[18]. Moreover, in the framework above, it may be that high-skilled workers may be able to utilise gains from task integration, or they presumably have more versatile work preferences, while low-skilled may not. Particularly, some low-skilled workers may not even be able to perform multiple tasks.

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[18] A considerable amount of literature (selection effort, matching models, wage premium, signalling theory etc.) addresses the question of finding the right person for the right job.

Therefore, the model offers an explanation for skill-biased technological change. There is a growing body of evidence for firms' increasing worker skill requirements. Internationally, it appears that during the last decades the relative demand of skilled and educated labour has increased substantially, as evidenced by rising earnings inequality in the US and the UK and an increase in the relative unemployment rates of unskilled labour elsewhere in Europe (Bauer - Bender 2002). In the Finnish context Huttunen (2002) finds that the skill structure of labour demand in Finnish private sector labour markets has shifted towards highly-educated workers in 1988-1998. In addition, Ilmakunnas and Maliranta (2002) find that in Finnish manufacturing plants the job creation rate was higher in 1988-1994 during both recession and recovery for plants where workers have higher education levels. These plants, however, also experienced high job destruction rates and worker turnover rates.

The model shows how employment dispersion may appear because of technological change, education and training. It specifies how changes in production and information technologies, and rising education and training may be expected to affect the dispersion of wages and employment opportunities together with reorganisation of work. As a result, labour demand may shift from low- and middle-wage occupations and skills toward highly rewarded jobs and tasks, requiring training, autonomy or management ability. On the other hand, technological development may reduce the transferability of skills between jobs. For example, some high technology areas may require extensive knowledge on narrow issues, whereby returns to specialisation may increase rather than fall as specialisation grows. Therefore, the question of increasing versus decreasing labour specialisation remains in the end an empirical question. The model does, however, shed light on both developments.

4 KNOWLEDGE CREATION AND COMMUNICATION IN ORGANISATIONS

The model of Lindbeck and Snower in the previous chapter described the optimal degree of labour specialisation from the point of view of an individual worker. The optimal organisational form was then derived from this optimisation problem. The authors sought to explain organisational changes associated with reductions in the degree of labour specialisation within firms, and thereby a blurring of occupational boundaries (Lindbeck - Snower 2000). Therefore the model did not address the role of information sharing because it concentrated on the allocation of tasks on an intrapersonal level (one individual performing one or more tasks) rather than on an interpersonal level (a group of individuals performing a broader or narrower range of tasks). Information sharing is in turn taken into account in the following model of Greenan and Guellec (1994), where the organisational form turns out to depend also on the costs of communication.

Greenan and Guellec (1994) describe in their model how a firm's organisation can affect its capacity to create new knowledge on technology. The authors recognise that human capital accumulation has two sources: "scientific knowledge" accumulation, and "practical knowledge" accumulation. Scientific knowledge is derived from R&D activity as emphasised by new growth theory, and it is used to produce product and production innovations. Practical knowledge on the other hand is knowledge on technology, which is required in the production process. The Greenan - Guellec model shows how certain organisational aspects may affect the firm's capability to create practical knowledge and thereby mastering technology and technical change. Furthermore, technical change may also affect the firm organisation. Specifically, the organisational feature addressed is the coordination of knowledge making and information sharing in the production and innovation processes within the firm.

The model sees the firm as an organisation, where collective knowledge on manufacturing, that is, mastering and improving existing technology, is built from learning-by-doing. In other words, in order to be mastered, technology has to be subject to a learning-by-doing process. Learning-by-doing, and the sharing of the resulting knowledge, requires coordination between workers within the firm. The model opposes two types of organisations, which differ in how coordination of this collective knowledge is structured within the firm. In a centralised organisation, knowledge is restricted to specialized workers (e.g. engineers). The specialised knowledge workers design the tasks, which are performed by other workers. In a decentralised organisation, by contrast, every worker participates in learning and information sharing. Thereby, the two organisation types correspond to two different types of division of labour, and the division is made on the basis of access to knowledge on technology. The centralised organisation refers to the traditional hierarchies in a Tayloristic or Fordist manner, and the decentralised one refers to Japanese decentralised organisations. (Greenan - Guellec 1994.)

The key point in the model is that knowledge created in the two coordination styles differs by its nature, and thereby also by costs and benefits associated with it. The crucial factor affecting the relative efficiency of the coordination styles turns out to be the economy's technological level, which is depicted by the economy's product range. The model shows that the relative efficiency of the two coordination styles may change when the differentiation of products grows. The centralised organisation is more efficient when the technological level, depicted by the product variety, is low, whereas the decentralised one becomes more efficient when the technological level is higher. (Greenan - Guellec 1994.)

This chapter is organised as follows. Scientific knowledge and practical knowledge, and learning-by-doing are discussed in section 4.1. The relationship of organisation and the costs and benefits of collective learning is addressed in section 4.2 in a single firm static framework. This discussion explores the relative efficiency of the two coordination styles. Section 4.3 extends the analysis into a general equilibrium framework, where the equilibrium number of goods is associated with the prevailing coordination style in firms. Then the issue of product differentiation and organisation is further discussed in a dynamic framework. Section 4.3 combines two different aspects to knowledge accumulation, technical change and endogenous growth: the dynamics of in-laboratory science and learning-by-doing. The former is likely to generate innovations; the latter determines the ability of firms to implement and master new technologies in the production process. Section 4.4 concludes. The rest of this chapter draws from Greenan and Guellec (1994) unless otherwise mentioned.

4.1 Knowledge and technology

Greenan and Guellec stress the importance of the firm's organisation in how it can master technology and cope with technological change. The firm's organisation determines how knowledge creation, that is, learning, and knowledge sharing takes place within the firm. The significance of learning and information sharing becomes evident when we identify knowledge sharing among people as the source of product and production innovations[19]. Therefore knowledge on manufacturing in a firm has a collective dimension, which is shaped by firm organisation. It is distinctive in the Greenan - Guellec model that the rate of knowledge accumulation in the firm does not depend only on the fraction of resources devoted to research and development (R&D), but on how much knowledge is created by "normal" economic activity, that is, learning-by-doing. Hence, the authors distinguish between two types of knowledge corresponding to these two sources: scientific knowledge and practical manufacturing related knowledge. These will be discussed in the following.

4.1.1 Scientific knowledge

The particular feature of scientific knowledge is that it is a public good, which can be used and communicated without costs. A public good is a good that has to be provided in the same amount to all affected consumers. More specifically, goods that are not excludable and are non-rival are public goods. Rivalry is a purely technological quality. A good is non-rival simply if one person's consumption does not reduce the amount available to other consumers. Excludability is determined by technology and the legal system. A good is excludable if the owner can exclude others from using it. A simple example of a not excludable and non-rival good is basic scientific research. The use of, say, a mathematical formula does not preclude someone else's use of it, and once it is published it is available to anyone. The general nature of scientific research facilitates its circulation among many

[19] The relationship between technical change and learning has been addressed by Arrow (1962), who ascribes technical change to experience, that is, learning-by-doing.

users: the cost of communicating is low because people who have produced it and those who use it have the same language. (Romer 1990.)

The public good features have also been ascribed to knowledge on technology. This has been emphasised by the new growth theory with important implications, as the possibility of sharing without limits to technological knowledge makes research a fixed cost, generating increasing returns to scale. Romer (1990) identifies in this process the source of long-run growth[20].

In the single firm framework of the Greenan - Guellec model in chapter 3 the focus is, however, on the within-firm coordination of knowledge, so the aspects of non-rivalry and non-excludability are also considered within the boundaries of a firm. Technological knowledge on manufacturing is non-rival, as the use of some technology does not preclude its use somewhere else. For example, the design of a product can be used as many times as is needed. Technological knowledge within the firm is also non-excludable, when all researchers have access to it. This line of thought is examined in the model through an endogenous growth framework.

4.1.2 Manufacturing related knowledge

Practical knowledge on manufacturing is quite different by its nature. As technological knowledge is created by specific groups of workers (engineers or researchers), practical knowledge is cumulated from learning-by-doing within the firm. The idea of learning-by-doing is that the efficiency of labour in a task increases by repeating that task (Arrow 1962)[21]. This is often addressed through the so-called learning curve, which relates negatively the volume of production cumulated over time and the unit cost. In fact, the exact mechanisms of learning-by-doing are seldom explored and it is generally presented in a reduced form, through a production function with increasing returns to scale, or through a declining unit cost function.

Greenan and Guellec argue that such reduced forms of learning-by-doing are justified when it is supposed that the relationships are given to the agents; that the parameters are purely technological ones, and are not affected by agents' behaviours. This rather mechanistic view sees learning merely as a by-product of doing, on which agents have no influence. The authors claim, however, that learning-by-doing is not an exogenous phenomenon. Instead, it is conscious activity in which firms invest. Because resources are invested into learning-by-doing, it will also be subject to profit maximising decision-making. Therefore, learning-by-doing is an endogenous phenomenon. Furthermore, the fact that learning-by-doing is endogenised means that the learning curve is affected by various economic variables. Because agents react to economic variables, their behaviour in turn modifies the parameters reflecting learning in the production function.

The collective dimension of learning stems from the fact that the productivity of each worker is partly determined by technical knowledge created and shared by others within the firm. Collective technical knowledge on manufacturing may improve for instance the

[20] Because of non-convexities brought about by a non-rival input, it follows that price-taking behaviour cannot be supported.

[21] Lucas (1993) also defines learning-by-doing as human capital accumulation on the job.

efficiency of the work organisation by better allocation of tasks, or procedures to come by with day-to-day problem solving. Therefore, practical knowledge resembles a local public good, because its use is shared among many people. Practical knowledge is local, because it is by definition embedded in its practical conditions and it can be poorly applied to different conditions in another context. This seems plausible, as there is a close connection between the technology used and the knowledge that improves its efficient use, and therefore the knowledge has mainly local relevance.

Another factor making knowledge resulting from learning-by-doing more local is communication costs. These may be derived from different sources. Bounded rationality of individuals brings about noise and loss of information in the circulation of information. Communication is also time-consuming, and time devoted to communication is then away from direct production time. Finally, the communicated information needs to be in a form, which is understandable to many people. Therefore, there are costs related to the elaboration of information into a codified form. This also means that when the costs of codification become too high, knowledge will remain tacit.

Consequently, practical knowledge departs from scientific knowledge in a decisive way: in addition to the fixed cost of creating knowledge, it incurs also communication costs. This is an important point in the model. Manufacturing related knowledge is built inside firms through information sharing. Information sharing is a costly activity, as time is consumed in the elaboration and communication of information. This time is taken from direct production time, and profit maximising firms try to find the optimal time allocation between information sharing and direct production. In other words, knowledge is subject to economic computation, and firms attempt to rationalise learning-by-doing.

Greenan and Guellec argue that the rationalisation of knowledge is accomplished through coordination of the learning-by-doing process, and this is precisely what they aim to describe. They describe how manufacturing related knowledge is built inside firms and in what ways it affects traditional production functions. The authors distinguish between two extreme types of coordination of learning-by-doing. In the centralised model learning-by-doing is minimised, whereas in the decentralised model all workers participate in the learning-by-doing process. The next chapter explores coordination of learning-by-doing from this approach.

4.2 A model of coordination of learning within organisations

In the following manufacturing related knowledge is addressed through a modelling of the learning-by-doing process in two types of organisations. It was suggested earlier, that in order to be mastered, technology has to be subject to a learning-by-doing process. The efficient use of technology, that is, how to use machines efficiently and fix technical problems, has to be found in practice. Designers of technology (i.e. engineers) may not be able to foresee the practical issues related to the design of work with that technology, which have to be dealt with during production. This is the type of information referred to as manufacturing related knowledge.

The handling of information on manufacturing can be carried out in different ways. The firm may choose which workers gather and process information, and how they coordinate in order to share information and learn about technology. The Greenan - Guellec model distinguishes between two types of coordination, which define two types of organisations: a centralised organisation and a decentralised organisation. The centralised organisation resembles the traditional hierarchical mass production organisation, where the division of work is strictly defined. The decentralised organisation is influenced by the Japanese horizontal industrial model, where workers participate in learning and decision-making.

In the centralised model (C-model) knowledge is built according to a "learning by observing what is being done" process. The firm employs two types of workforce: (1) those who gather and process information about technology (engineers) and (2) those who participate directly in production (production workers). Workers in the first category are specialised in knowledge making, whereas workers of the second type do not participate in knowledge making. Therefore, learning is minimised, as it is restricted only to some workers. Once information has been gathered and processed by the knowledge workers, coordination takes place in a hierarchical way. The knowledge workers have the authority to make decisions concerning production, and the production workers have to comply with these decision. The model is therefore centralised, as decisions are taken by other people than direct producers.

In the decentralised model (D-model) knowledge is built from a direct learning-by-doing process. All workers participate in information processing and information sharing, and they collectively aim to master technology. Workers have to monitor the production process themselves and come up with improvements or solutions to problems. This takes place through a worker's own experience (direct learning-by-doing), and through information sharing with other workers. No authority is involved as each worker decides himself what is the best way to carry out his job. Consequently, the decentralised work organisation requires a skilled work force, whereas the work force in the C-model only needs only to be able to carry out orders[22].

The key point in the Greenan - Guellec model is that knowledge built in the two coordination styles differs by its nature. The knowledge built in the C-model resembles scientific knowledge. It is general and codified knowledge, although its relevance is local and focused within the boundaries of the firm. This knowledge is in the form of simple instructions, which the authors call "standards". Knowledge built in the D-model is in contrast composed of "raw", sometimes tacit information. The firm faces a trade-off between two types of knowledge according to their relative efficiency. Consequently, costs and productive efficiency associated with the two knowledge types have to be taken into account.

Most importantly, there are costs associated with information sharing, because time devoted to the elaboration and communication of information is taken from direct production time. As a result, firms have to rationalise learning-by-doing so as to keep its costs down. In a centralised organisation, this is achieved by restricting learning to only some employees, who codify the information into simple instructions before communicating it to the workers. The communication channel is straightforward and communication costs are relatively small. In a decentralised organisation, on the other hand, each worker participates in collective learning. Consequently, information sharing becomes costly. Multiple communication channels are required to communicate the information to other workers, as there are no hierarchical communication channels. Information is also in a weakly codified and

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22 This will not be addressed in the model, as labour is supposed to be homogeneous.

localised form and it may be difficult and time-consuming to communicate onwards. Finally, the information flow may be very large and it may be costly to assort the relevant information.

In the C-model knowledge workers have two tasks. First, they have to process the information on production and build a "general theory" of production, on which they base their decisions. Then they have to codify the decisions into a simple form, which the production workers understand without knowing the general theory. This codified information is expressed as rules, manufacturing standards, technical norms, or it can even be embedded in machines, which set the division and pace of work. The authors use "standard" as the term to represent this type of codified knowledge.

The information processing and codifying process is costly since the knowledge workers have to distinguish the relevant facts from a large information flow and to invent specific codes to transmit them onwards. The compensation for this is that once this investment has been made and the knowledge is in a suitable form, it can be used again and again without supplementary cost. Therefore, it is general enough to be non-rival and not excludable within the firm, and so it has the status of a public good within the firm. This generality has, however, a drawback; the standards cannot take into account all local questions of production, for example, very specific operations or rare difficulties.

The costs associated with information include both its production costs and its communication costs. The cost (u_c) of producing one standard in the C-model is considered to be fixed, since it is independent of the number of people who use it. This cost is the *time* knowledge workers spend designing a standard. It is made up of the time it takes for the engineers to process and codify information into a straightforward instruction for the production workers. Once the standard is created, it can be communicated with a very low cost, because the information is in such a simple and general form. The messages sent to the workshop are codified, straightforward orders, as workers do not need to understand the whole production process. The authors argue that an assumption of zero communication costs is a relevant approximation. Therefore, the only costs associated with information in the C-model are its production costs, which are independent of the number of workers, l. The amount of information is depicted by m, which is the number of instructions needed in the production. The total cost of both producing and communicating m instructions in the C-model is:

$$C_c(m) = mu_c. \tag{12}$$

Knowledge built in the D-model differs markedly from that built in the C-model. Knowledge in the D-model is local knowledge, and it is codified weakly or not at all. It is built from local information, know-how, and it may even be shared in very specific and informal ways such as through demonstration. Therefore, the communication of information in the D-model is costly. The advantage of the D-model is that a worker can react directly to a problem in the production process, whereas in the C-model some time flows, as the information has to circulate to the knowledge workers and back. In the C-model knowledge workers have to first become aware of the problem, and then come up with a solution and translate into simple instructions before the production workers can react to the problem. This makes the production of information in the C-model more costly than in the D-model. Therefore, there are also fewer people working on the creation of information in the C-model, as this activity is costly.

In order to compare the C-model and the D-model, information units are measured as efficiency units. According to the above reasoning, the fixed cost of knowledge production is higher in the C- model (u_c) than in the D-model (u_d):

$$u_c > u_d. \tag{13}$$

The authors argue that the exposition of the measure of information as efficiency units is entitled as they are derived from the production function. Standards and local information have the same measure when they show an identical contribution to productivity. Therefore, an efficiency unit of information is a unit of local knowledge that leads to the same level of productivity as a standard. Specifically, u_d is the quantity of time devoted by each worker in the direct learning-by-doing process to produce knowledge, whereas u_c is the total working time of only the specialised workers.

To give a simple example of efficiency units of information, say that in the C-model a worker can assemble a cell phone when he has the relevant components and 10 sheets of instructions, drawn up by the engineers. In the D-model, by contrast, a worker can assemble a cell phone when she has the relevant components and she gets five hours of teaching, that is, information sharing, from a co-worker, and ten hours of learning-by-doing by herself. Therefore, ten sheets of instructions in the C-model have the same contribution to productivity than five hours of information sharing and ten hours of direct learning-by-doing in the D-model. The production of information is, however, more costly in the C-model, as the few knowledge workers have to process all relevant information on the assembly of cell phones and translate it into sheets of instructions. In the D-model workers create knowledge simply through a learning-by-doing process and through information sharing, whereby information is ready for production use.

The locality of information in the D-model makes its use for general issues very costly. Practical information in a weakly codified form can be very difficult to understand and apply at a distance from the original location where the information was built. This may result in that similar solutions have to be invented several times. Even if a general solution is discovered, then a multitude of communication channels have to be opened to inform the rest of the shop floor, so communication is very costly on this point of view too. Therefore, the cost of communicating practical information is high and increases with the number of workers involved. The total cost of producing and communicating m units of efficient information in the D-model can be expressed as:

$$C_d(m) = mu_d l^\gamma \qquad 0 < \gamma < 1, \tag{14}$$

where m is the quantity of efficient units of information and u_d the production cost of one unit of information. The term l^γ represents the communication costs, where l is the number of workers, and γ is a parameter representing the difficulty to communicate. It consists of communication costs and excess information flow. The cost of information increases with l, but $\gamma < 1$ in order to avoid excessively decreasing returns to scale.

If we now return to the previous cell phone assembly example, we can see that information sharing is very cheap in the C-model. Say a new worker is hired, and he has to be trained to assemble cell phones. Then the engineers only have to copy the instruction sheets and give them to the new worker. In the D-model, by contrast, the new worker needs 5 hours of personal instruction from some other worker. On the other hand, whenever something unexpected happens, the workers in the D-model can react to it themselves, use their knowledge on production and learn to create a solution. They may also come up with efficiency improving ways to assemble the cell phone. In the C-model the workers only know how to work according to the fairly general instructions, and the improvements are only brought along by the engineers' costly instructions.

The firm's production function has knowledge as an argument, and labour is the only other production factor. The production function is:

$$x_j(m,l) = m^{\alpha}(l - C_j(m)) \qquad 0 < \alpha < 1, \;\; j = c,d. \tag{15}$$

Therefore, production depends on the quantity of knowledge (m) with an elasticity of $\alpha < 1$, and on the total labour force involved in direct production (l), excluding the costs associated with time spent on processing and communicating information $(C_j(m))$. Labour input in production, depicted by (l), has a unitary elasticity in the production function. The assumption decreasing marginal product of knowledge is justified with respect to both types of knowledge. First, when knowledge takes the form of a standard, the most relevant information will be processed first, and the marginal efficiency of standards will presumably decrease when more standards are created. Second, as practical knowledge is built through direct information sharing on the shop floor, the relative "uselessness" of information is likely to increase as the quantity of information grows.

The firm chooses an optimal allocation of the total working time between direct production and investment in knowledge production, the number of workers being given[23]. Thus, the control variable is the quantity of knowledge used as an input in production. The authors model this firm's decision-making problem in a static single firm profit maximisation context, where the firm produces only one output. Price, wage and labour force are assumed to be given to the firm and therefore the firm's profit maximisation is equivalent to the maximisation of production.

We derive the first order conditions by placing the derivative of the production function with respect to m to zero. Thus, the optimal quantities of information in both styles of coordination are:

$$m_c^* = \frac{\alpha}{(1+\alpha)u_c} l \tag{16a}$$

and

$$m_d^* = \frac{\alpha}{(1+\alpha)u_d} l^{1-\gamma}. \tag{16b}$$

The following reduced forms of the production functions are derived from equations (12), (14), (15) and (16):

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[23] Working time for each worker is constant and therefore the firm has a fixed amount of total working time.

$$x_c = \beta_c l^{\alpha_c} \tag{17a}$$

$$x_d = \beta_d l^{\alpha_d}, \tag{17b}$$

where α_c and α_d are:

$$\alpha_c = 1 + \alpha, \tag{18a}$$

$$\alpha_d = 1 + \alpha(1-\gamma), \tag{18b}$$

and β_c and β_d are:

$$\beta_c = \left(\frac{\alpha}{(1+\alpha)u_c}\right)^{\alpha} \frac{1}{(1+\alpha)}, \tag{19a}$$

$$\beta_d = \left(\frac{\alpha}{(1+\alpha)u_d}\right)^{\alpha} \frac{1}{(1+\alpha)}. \tag{19b}$$

The term $\alpha_j, j = c, d$ represents the elasticity of production with respect to the labour force. Because the cost of knowledge per labour unit is independent of the quantity of labour involved in production, the parameters of the production function, α_j and β_j, do not depend on l. Moreover, as $u_c > u_d$ and $0 < \alpha < 1$, we have:

$$1 < \alpha_d < \alpha_c, \tag{20}$$

$$\beta_c < \beta_d. \tag{21}$$

Therefore, equations (18a) and (18b) show, there are increasing returns to scale in both styles of coordination $(\alpha_c, \alpha_d > 1)$, as there is a fixed cost associated with knowledge making. From equation (20) we can see that returns to scale are higher in the C-model than in the D-model, because of the lack of the parameter representing the difficulty to communicate (γ) in α_c. In the C-model the excess information is limited and the communication costs do not increase with the number of workers. Therefore, when the labour force is large, the C-model will have a higher productivity. But equation (21) shows that the productivity associated with the D-model will approach that of the C-model when the labour force is small. With a small labour force the low cost of processing information overcomes the high cost of communicating it. Consequently, there is a certain value of l (l_s), beyond which the relative efficiency between the two models switches from the D-model to the C-model, as depicted in figure 4.1. We get this threshold from equations (17a) and (17b):

$$l^s = \left(\frac{\beta_d}{\beta_c}\right)^{\frac{1}{\alpha_c - \alpha_d}}. \tag{22}$$

The authors say that this represents a trade-off between global and local efficiency, between scale economies and flexibility, between the ability to manage large and small product batches. It is noteworthy that it is the size of the labour force that determines the returns to scale, not the quantity of output produced. In a firm with a small labour force low communication costs do not outweigh the high costs associated with the production of scientific knowledge, and the firm chooses and decentralised organisation. In contrast, in a large firm the low costs associated with practical knowledge do not outweigh the high communication costs associated with that type of knowledge, and the firm opts for the centralised organisation. Therefore, if we assume that there is no cost in changing the organisation and firms are fully ware of both styles of coordination, the firm's choice of coordination style boils down to a simple condition: the C-model, if the firm is large; the D-model, if the firm is small.

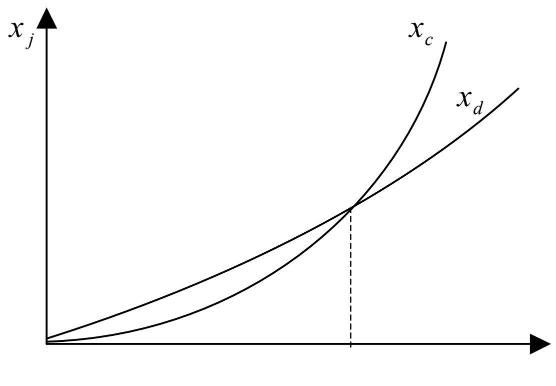

Figure 4.1. Production functions of the two coordination styles.

4.3 Knowledge creation and endogenous growth

In this chapter the approach will be in a static general equilibrium framework. The analysis is influenced by Dixit and Stiglitz (1977) and Krugman (1980), where prices and quantities of goods are equilibrium variables. The model provides the equilibrium prices and the number of goods in an economy, and most importantly, it will show how the latter depends on firm organisation.

There are assumed to be a large number of goods in the economy, all of which enter symmetrically into demand. There exists a representative consumer with a taste for diversity, which is expressed in the following utility function:

$$U = \sum_{i=1}^{n} c_i^{\theta} \qquad 0 < \theta < 1, \tag{23}$$

where c_i is the quantity of good i which is consumed, n is the number of available goods and parameter θ represents the consumer's taste for diversity. It follows that each good is consumed in the same quantity. Consequently, the elasticity of utility to the quantity of goods is $\theta,$ whereas its elasticity to the number of different goods is 1. Since $\theta < 1,$ the representative consumer prefers an increase in the number of different goods to an increase in this quantity[24].

Each firm produces only one good, with labour as a factor of production. Since the same production function is used as in the previous section, knowledge is also implicitly a production factor. Labour input incurs a fixed cost and a variable cost. The fixed cost represents the invention cost of a good, which is represented by the resources devoted to R&D, whereas the variable cost is dependent on output. Total costs l_i^T of each good are the sum of the fixed and the variable costs:

$$l_i^T = l^R + l_i, \tag{24}$$

where l_i is the number of workers on the shop floor, and l^R is the number of researchers needed to invent the good. The number of researchers needed is exogenous and the same for all goods. The labour force is assumed to be homogeneous: researchers and workers have identical skills. The production functions corresponding to the two coordination types from equations (17a) and (17b) are[25]:

$$x_i = \beta_j l_i^{\alpha_j} \qquad i = \{1, n\},\ j = c, d, \tag{25}$$

where x_i is the volume of production of good i, which may differ for a given l_i, depending on the coordination style of the firm.

There is a number of L consumers and producers, who are the same persons. It is assumed that output of each good must equal the sum of individual consumptions, and the equilibria in the goods markets can be expressed as:

$$x_i = Lc_i \qquad i = 1, \ldots, n, \tag{26}$$

where output is the consumption of the representative consumer times the labour force. Full employment is also assumed, so that the total labour force must just be exhausted by labour used in production. Thus, equilibrium in the labour market is:

$$L = \sum_{i=1}^{n} l_i^T. \tag{27}$$

Because of the increasing returns to scale, the only stable market structure is a monopoly in each good. Competition takes place only between firms producing different substitutable goods: it is of Chamberlin type[26]. The assumptions of the Chamberlinian monopolistic competition include that firms maximise profits, but that there is free entry and exit of firms, which drives equilibrium profits to zero. Entry is a matter of finding the right differentiated niche, and a monopoly seeks to deter entry in its niche by investing in R&D

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24 The consumer consumes a bit of every available good instead of consuming only his most preferred product.
25 Hence the cost of knowledge making derives from two sources, from learning-by-doing and from R&D.
26 Chamberlin (1933) introduced this type of monopolistic competition.

(Spence 1976). Therefore, whatever returns the firm may receive above the production costs, it invests them into R&D to keep the monopoly status[27].

The Chamberlinian approach has the special characteristic that even though it features imperfect competition, an equilibrium is determined because of the special nature of how demand rules out strategic interdependence among firms. Because firms can differentiate their products without costs, and all products enter symmetrically into demand, two firms will never want to produce the same product and each good will be produced by only one firm. Each firm has then no direct neighbour in the product space. At the same time, if the number of goods produced is large, the effect of the price of one good has a negligible effect on the demand for any other good. As a result, each firm can ignore the effects of its behaviour on other firms' behaviour[28]. (Krugman 1980; Tirole 1988, 287-299.)

Since all goods have the same features on both demand and supply side, the same quantity of each good is produced at the same price at the equilibrium. Thus, the firms have the same level of productivity, that is, the same type of organisation in all firms. Because of this symmetry, the index *i* will be omitted in the following.

We proceed now with the consideration of consumer behaviour. The representative consumer maximises her utility (equation (23)) with respect to a budget constraint. The first-order conditions from the maximisation problem are:

$$\theta c^{\theta-1} = \lambda p, \tag{28}$$

where p is the price of the good and λ is the shadow price on the budget constraint, that is, the marginal utility of income. Equation (28) can be rearranged together with the equilibrium condition in equation (26) to show the demand curve the firm faces:

$$p = \theta \lambda^{-1} (x / L)^{\theta-1}. \tag{29}$$

Provided that there are a large number of goods being produced, the pricing decision of any one firm will have a negligible effect on the marginal utility of income. Thus, equation (29) implies, that the firm faces a demand curve with an elasticity of $(1/(1-\theta))$. The firm sets its price to maximise profits:

$$\underset{p}{\text{Max}}\; px(p) - w\left[l(x(p)) + l^R\right], \tag{30}$$

from which we obtain the equilibrium prices:

$$w / p = \theta \mathrm{d}x / \mathrm{d}l = \theta \beta_j \alpha_j l^{\alpha_j - 1}. \tag{31}$$

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27 Thus, price equals average costs and profits are zero.

28 This absence of cross-effects has been widely criticised. Except in few cases, existing products compete with a few products, or when they do not, the assumption of zero profits does not hold. The point of these assumptions is, however, to simplify analysis in order to study the number of products offered by the economy. (Tirole 1988, 287-288.)

Taking into account that free entry drives monopoly profits to zero and the equilibria conditions in the markets, we get the equilibrium number of goods:

$$n = \left[(1-\theta\alpha_j)L\right] / l^R . \qquad (32)$$

Therefore, the determinants of the equilibrium number of goods in the economy are the size of the economy represented by the size of the labour force L, consumer taste for diversity θ, the elasticity of production with respect to labour force α_j, and the size of the innovation cost l^R.

A larger economy can support a higher number if goods given the zero-profit condition and the fixed-cost associated with innovation. An increase in consumer taste for diversity is reflected by a decrease in θ, which raises the equilibrium number of goods. The elasticity of production with respect to the labour force α_j implies a trade-off between more diversity and a bigger quantity of each good. The size of this trade-off depends on j, the coordination style in the firm. The higher are the returns to scale in production (a higher α_j), the larger quantity of production has to be given up in order to increase product diversity. Returns to scale are higher in the C-model than in the D-model (equation (20)), so the equilibrium number of goods will be higher D-model:

$$n_c < n_d . \qquad (33)$$

Thus, an economy, where firms are organised centrally will provide a smaller diversity of goods than an economy with decentralised firms.

The following discussion extends the analysis into a dynamic framework of endogenous growth in order to examine the relationship between product differentiation and organisation. Some additional assumptions are needed to concentrate on this relationship. First, growth is defined as an increase in the number of different goods n, which will be indexed by time t[29]. It is further assumed that each type of good is produced and sold during one period only. Thus, all goods are new in the beginning of each period, and learning-by-doing embodied in each good disappears from one period to another. This means that learning is "localised", that is, restricted to each good (see Stiglitz 1987).

Second, the invention of new products is a result of research activity. This is modelled after Romer (1990). New goods are invented in the R&D activity by using previously accumulated knowledge, which is embodied in past goods. This knowledge is a public good like scientific knowledge discussed earlier: it is available to all researchers. Therefore, the productivity of each researcher, represented by the number of product innovations, grows as the number of existing goods grows.

A constant marginal productivity of knowledge is assumed in the innovation activity. This means that a given amount of research activity brings about a number of innovations proportional to the amount of knowledge, whatever this amount may be. Therefore, there is a perpetual increase in the accumulated stock of knowledge, which is a characteristic out-

29 To simplify the analysis, productivity is not addressed. The role of learning-by-doing and specialisation of labour in generating economic growth understood as increasing productivity has been addressed by Yang and Borland (1991).

come in the endogenous growth theory compared to neoclassical theory. The number of innovations per researcher in period t is δn_{t-1}, where δ is a scale parameter representing the proportional increase in innovations to the stock of existing knowledge. Then the total number of product innovations n in the economy in period t is:

$$n_t = \delta n_{t-1} L_t^R , \tag{34}$$

where L_t^R is the total number of researchers in period t. The linear relationship between innovations n_t, and the existing stock of knowledge n_{t-1} and the number of researchers L_t^R is largely made for analytical convenience. Linearity in n_{t-1} is what makes unbounded growth possible, which is here more of an assumption than a result of the model. If L_t^R were replaced in equation (34) by some concave function of L_t^R, that is, the marginal product of researchers would not grow in proportion to the existing stock of knowledge; labour force would shift from research into manufacturing as the stock of knowledge grows. Romer (1990) concludes that there is no evidence from recent history to support the belief that opportunities for research are diminishing. Moreover, we are primarily interested in how does the organisational form affect the growth rate of n_t. Therefore the specification here, in which a constant growth rate is feasible, is justified. (Romer 1990.)

As in the previous chapter, the fixed number of researchers required to produce one invention is l^R, which can be expressed as:

$$l_t^R = L_t^R / n_t . \tag{35}$$

Using equations (32), (34) and (35) and by rearranging we get the growth rate of the number of goods in period t:

$$(n_t - n_{t-1})/n_{t-1} = \delta L(1-\theta\alpha_j) - 1 \tag{36}$$

$$\text{if } L > 1/\delta(1-\theta\alpha_j).$$

Equation (36) shows that the growth rate of the equilibrium number of goods increases with the size of the economy L, and the consumer taste for diversity, as θ decreases when preferences become more favourable to diversity. The growth rate decreases with the elasticity of production with respect to the labour force, α_j. The negative relationship between product variety and returns to scale was noticed also in the previous chapter and the same reasoning applies here too: the higher are the returns to scale, the larger is the loss in quantity needed for a given increase in the number of products. As a result, the growth rate of new products is smaller. Because none of the variables on the right side of equation (36) is dependent on time, the growth rate is constant over time and there exists a steady-state equilibrium growth rate in the model. Therefore, the time index t can be omitted. If we denote g_c the growth rate in the C-model and g_d that of the D-model, the following inequality holds:

$$g_c < g_d . \tag{37}$$

Thus, the same logic than in the static framework applies also here: there is a trade-off between higher diversity and a larger quantity of each good, and the coordination style within firms determines the size of the trade-off. Diversity is sought if the costs in terms of quantity produced of each good are smaller, which is the case in the decentralised style of coordination. In the centralised model the loss in quantity of each good produced is larger for a given increase in diversity. Therefore the growth rate in the number of goods is higher in the D-model than in the C-model.

The difference in product innovation between the two coordination styles reflects the difference in the innovation effort, that is, the share of labour force devoted to R&D. From equations (34) and (36) we get:

$$L_j^R = (1-\theta\alpha_j)L. \qquad (38)$$

As $\alpha_d < \alpha_c$, the share of labour force devoted to R&D is larger in the D-model.

What are the implications for the economy's dynamics when firms face a choice of organisational form? In the static framework the firm's choice of coordination style depended on the size of its labour force. In a general equilibrium framework the size of labour force depends further on the size of the economy and the number of goods:

$$l_t = \theta\alpha_j L / n_t. \qquad (39)$$

The size of the firm's labour force (l_t) in period *t* is inversely related to the number of goods (n_t). In other words, a small number of goods is associated with large labour forces in firms, with their size decreasing with the increase in *n* coming from the innovation process. The key point is that the relationship between *n* and *l* depends on the coordination style. This relationship is depicted in Figure 4.2.

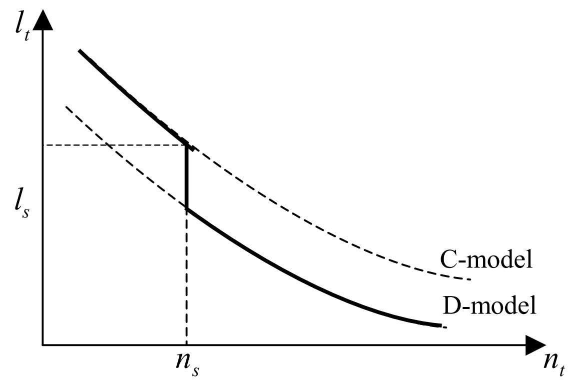

Figure 4.2. From the C-model to the D-model

Consider an economy with a relatively low technological level, particularly, in which the number of goods is $n < n^s$. This number of goods corresponds to the size of the labour force l^s, the level beyond which the firm chooses the C-model specified in equation (22).

The firm keeps its centralised coordination style until the number of goods grows sufficiently to make the D-model (and a smaller labour force) more efficient, which is until n reaches n^s. From equations (39) and (22) and placing $j = c$ we get the critical value n^s:

$$n^s = \left(\frac{\beta_c}{\beta_d}\right)^{\frac{1}{\alpha_c - \alpha_d}} \theta \alpha_c L. \tag{40}$$

When n rises beyond n^s, profit-maximising firms change their coordination style. The change into the D-model brings about an increase in the labour force devoted to R&D (see Figure 4.3), and a decrease in the total labour force devoted to production.

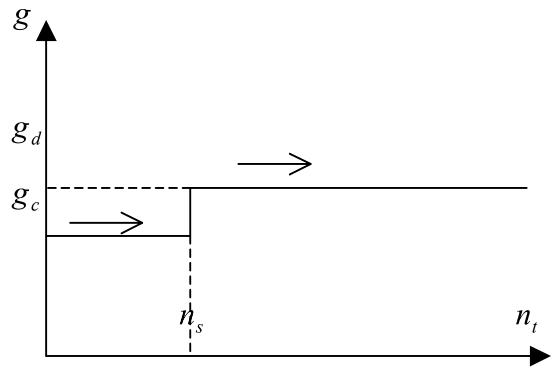

Figure 4.3. Product innovation growth.

In sum, the differentiation of goods makes the decentralised model more efficient relative to the decentralised one. The key variable is the size of the labour force involved in the production process of any good, which declines when the number of differentiated goods is higher in the economy. A smaller labour force mitigates economies of scale due to centralisation and the communication costs due to decentralisation.

4.4 Findings

The Greenan - Guellec model approached the issue of coordination of learning and information sharing within the firm on different levels. First, in the discussion in the single firm static framework the relative efficiency of the two types of coordination of knowledge creation, centralised and decentralised, was explored. The crucial factor determining the relative efficiency of these coordination styles turned out to be the size of the labour force. This rather simple conclusion was determined basically by the fact that the costs of communicating practical knowledge associated with the decentralised organisation become too large when the labour force grows. In a large organisation, it is more efficient to leave learning to only some workers, and share the information in a low-cost, simplified form. As a result, the optimal organisation structure of a large firm is hierarchical, and workers are either specialised in production or knowledge making. The workers specialised in knowledge making have the authority to make decisions concerning production. The production workers, by contrast, only perform their tasks without interfering in any way in the management of the production process.

Because only few workers in the centralised organisation process and communicate all the information, the production costs of information are high. In a decentralised organisation, by contrast, all workers participate in learning and information sharing. Workers contribute to the planning and development of the production process: they monitor the production process, fix problems and design improvements. Decision-making is decentralised as each worker decides himself what is the best way to carry out his job. Therefore, the production of information is cheaper in the decentralised organisation. Knowledge built in the decentralised organisation is local, specific and in a weakly codified form. Therefore, the communication of this type of information is costly, and the costs increase as the labour force grows. However, in a small firm the communication costs are smaller and they do not outweigh the benefits from the low costs of producing information associated with the decentralised model. As a result, in a small firm the decentralised organisation is more efficient, as the low cost of producing information overcomes the high communication costs associated with the decentralised organisational form.

In the general equilibrium approach the relationship of the organisational form and the equilibrium number of goods was examined. In this context there was another source of knowledge accumulation in addition to learning-by-doing: research and development (R&D). Whereas learning-by-doing brings about practical, manufacturing related knowledge, R&D creates knowledge, which resembles scientific knowledge and its public good features. Furthermore, as manufacturing related knowledge is crucial in the implementation and mastering of technology, R&D activity generates technical innovations. Therefore, there are two sources of knowledge accumulation, and both contribute to technical progress and growth.

The extension of the model into a general equilibrium framework revealed the relationship between the efficient form of organisation and the number of goods in the economy: the decentralised style becomes more efficient when the variety of goods is larger. When the variety of goods is large, the labour force dedicated to the production of each good is small, and we know already that a decentralised organisation is more efficient with a smaller labour force. In addition, the extension of the analysis into a dynamic framework revealed that the growth rate of new goods is higher in an economy where firms' organisations are decentralised. Thus, the analysis began with a focus on within the firm, but ended up on economy-wide developments.

One could say that the decentralised model refers to organisations, which rely on their human capital. It has been noted that an ever-larger share of the production capacity of the industrial countries consists of intangible capital, such as the human capital of workers and organisational structures (Böckerman 1996, 22). This does not, however, imply that a decentralised organisation is applicable only in firms, which depend on the knowledge created by their white-collar workers, for instance software producers. The authors obviously have an industrial manufacturer in mind, and they name car manufacturing as an example. Particularly, they emphasise the differences in the work organisations of horizontal Japanese and hierarchical American car manufacturing plants, and the increasing adoption of Japanese management practices in American car factories. As the trends in the auto industry resemble the developments portrayed in the model (increasing product variety and shortening production cycles), a smaller work force on each product batch has to be capable of working in varying situations. This highlights the importance of learning, and thereby the relative efficiency of the decentralised model as opposed to the centralised mass-production model.

5 CONCLUDING REMARKS

This thesis examined theoretically the efficient way to organise work within firms. The starting point for the study was a firm deciding the optimal design for its organisation. When choosing its organisational form, the firm has to decide how to allocate tasks among workers: Should workers specialise by task or should they perform multiple tasks? Should some functions be left to specialised workers, such as the coordination of the production process? Consequently, related questions arise, as information is required in coordination: How should the coordination of information processing and information sharing be organised? The answers to these questions provide the efficient degree of labour specialisation, which was investigated in the two theoretical models considered in this thesis. Chapter 3 examined the model of Lindbeck and Snower (2000), and chapter 4 discussed the model of Greenan and Guellec (1994).

The research questions posed in the beginning of this thesis were: What is the optimal way to organise work in a firm, particularly, what is the optimal degree of labour specialisation and under which conditions? How do learning and communication enter this analysis? How do different ways of organising learning and communication affect the optimal degree of labour specialisation? The Lindbeck - Snower model found that changes in technology or workers' human capital may increase the returns to learning across tasks relative to returns to learning-by-doing in specialised tasks. Therefore, an organisation with a small degree of labour specialisation may be optimal.

The Greenan-Guellec model found in turn that the optimal organisational form depends on the size of the labour force. A decentralised organisation is associated with low costs of producing knowledge and high communication costs, whereas the opposite holds for the centralised organisation. Therefore, among a smaller workforce the high communication costs do not outweigh the low production costs of information associated with the decentralised organisation. Furthermore, the relative efficiency of the two organisation styles may change in favour of decentralisation when the differentiation of products grows. It is noteworthy that in the Greenan-Guellec model it is the coordination costs that limit the returns to labour specialisation, whereas the Lindbeck - Snower model implied that also returns to learning across tasks may limit the relative returns to specialisation.

In the end the three aforementioned research questions relate to the problem of finding an organisational structure, which fits into a particular production system. In this respect the two models considered in this thesis have similar approaches. Both illustrate in what conditions (e.g. technology, labour force size and skill levels, consumer preferences) the traditional hierarchical form may not be the optimal way to organise work.

In the stereotypic Tayloristic or Fordist mass production system efficiency is derived from specialisation of labour and capital, and long production batches of standardised goods. A hierarchical organisation structure fits well into this type of production system. Workers specialise in carefully split single tasks, where they do not need to participate in the planning or improvement of the production process. The coordination of production is handled by workers specialised in processing information, who communicate it to the production workers. Hence, a hierarchical, centralised organisation minimises communication costs, because information flows only vertically and overlapping horizontal communication is minimised.

Learning that takes place in a centralised work organisation is aimed to improve a worker's efficiency in his specialised task. Learning takes place through one's experience in a task, that is, learning-by-doing in the sense of Arrow (1962). As time goes by the worker becomes more and more efficient and his productivity grows, as depicted in the Lindbeck - Snower model in chapter 3. On the other hand, since production workers do not supervise and design the production process, there has to be workers specialised in these managerial tasks. Access to information is restricted to these specialised knowledge workers, who process information and share it in a suitable form (e.g. instructions) to the production workers. Thus, the mass production model features advanced labour specialisation: first workers are specialised either in production or managerial functions, and then production workers further specialise by tasks. The latter type of specialisation was addressed in the Lindbeck - Snower model in chapter 3. The former kind of worker specialisation with explicit task heterogeneity between production workers and knowledge workers was addressed in the Greenan - Guellec model in chapter 4.

As proposed in the beginning of this thesis, the centralised organisation may not fit optimally into a production process not based on standardised mass production. A production process, in which efficiency is derived from responding to consumers' volatile demands by producing a large variety of goods in small batches, may require another type of organisation. This kind of a production system may require greater use of knowledge and learning from workers on the shop floor. When production is not highly standardised and production technologies are changing constantly, it may be too costly to centralise all information processing and decision-making to the management, away from the production workers. The decision-making process of a centralised organisation may be too slow and costly, and management may have far less relevant information than workers on many issues concerning the production process.

As a result, decentralised organisations, featuring such management practices as teamwork, job rotation and decentralised decision-making, have been emerging lately in the industrialised countries. These management practices basically aim to utilise gains from task integration, that is, from lowering the degree of labour specialisation. The Lindbeck - Snower model showed how task integration may be efficient as it permits workers to use information across tasks. Therefore, besides learning-by-doing in specialised tasks, there was another mechanism of learning in the model. Learning *across* tasks meant that a worker could utilise information gained in one task to improve her performance at another task. This intertask learning was represented by productivity returns to task complementarities, whereas returns to learning-by-doing were represented by productivity returns to specialisation.

The Lindbeck - Snower model showed how the optimal form of organisation is determined by the relationship between the returns to specialisation and the returns to task complementarities. In a traditional mass production organisation returns to specialisation are high relative to returns to task complementarities. Hence, it is optimal to have workers specialise by task. However, if returns to task complementarities outweigh returns to specialisation, it is optimal to have workers perform multiple tasks. In other words, a decentralised (i.e. holistic) organisation is more efficient than the Tayloristic organisation.

The Greenan - Guellec model offered a complementary view to the potential efficiency of the decentralised organisation. Greenan and Guellec pointed out that in decentralised organisations workers are also presumed to participate in information processing and decision-making, whereby traditional occupational boundaries between managerial and worker functions weaken. Hence, learning and communication that take place in decentralised organisations involve all workers as production workers participate in the monitoring of the production process, solve problems and make improvements.

Greenan and Guellec argued that production of information is less costly in the decentralised organisation because every worker creates knowledge through learning-by-doing. Therefore, every worker can react directly to a problem whenever one turns up. In a centralised organisation, by contrast, information has to flow through a costly information processing process, where few specialised knowledge workers handle the information. The disadvantage of the decentralised organisation is, however, that sharing of information is costly because information is often tacit and it has to be communicated horizontally. It turned out that the optimal choice between a decentralised and centralised organisation depends on the size of the firm's labour force. When the labour force is small, the firm chooses a decentralised form of organisation, since the low cost of producing information overcomes the high communication costs associated with the decentralised organisational form. The contrary applies to a large firm.

The central insight in this thesis was that the optimal degree of labour specialisation was in both models a result of the efficient way to organise work, given the returns and costs associated with learning. As a result, the analysis showed in what circumstances it is optimal to organise work in a centralised manner and when not. The relative efficiency of organisational forms was explored in the models by examining how learning and communication enter the firm's production function. It turned out that different styles of organising learning correspond to different degrees of labour specialisation. Labour specialisation in turn determines the organisational form.

One could reach the conclusion that the Lindbeck - Snower model worked on a more "micro" level than the Greenan - Guellec model. The Lindbeck - Snower model described learning on a worker level, from which the optimal degree of worker specialisation on a firm level was then derived. Because it concentrated on the essential features of intrapersonal task allocation, it did not address interpersonal task allocation and the collective dimension of knowledge accumulation in firms, as individual learning was "summed up" into firm level learning. In reality, however, learning involves significantly information sharing among workers.

Therefore, the insights from the Lindbeck - Snower model were complemented by the analysis of the Greenan - Guellec model, where communication was a significant part of the model. Greenan and Guellec sought to draw attention the mechanistic view of learning-by-doing often portrayed in economic literature. They argued that learning should not be considered as merely a by-product of doing, which can be represented as increasing labour productivity at a task as time devoted to that task increases. Instead, learning is essentially a collective phenomenon within the firm, because it involves costly information sharing among workers. Therefore, learning-by-doing is an endogenous phenomenon, which firms aims to rationalise by organising it among workers efficiently.

What is important is that as models showed, the costs and benefits of different styles of organising learning can vary in response to other economic variables, such as technology, the size of labour force and the level of human capital. For example, in the Lindbeck -

Snower model exogenous changes that increase returns to task complementarities (e.g. improved information technologies) may change the optimal form of organisation. Moreover, the Greenan - Guellec model showed that the relative importance of costs and benefits of different styles of coordinating learning might be altered by economy wide developments such as consumer preferences towards the variety of goods. In addition, in the Greenan - Guellec model the organisation style may also affect economy-wide developments: the variety of goods and growth rate. Thus, the Lindbeck - Snower model concentrated on supply-side elements; it showed how returns to learning within and across tasks enter the production function. The Greenan - Guellec model, on the other hand, took also demand side factors into account, since consumers' taste for diversity was addressed in the general equilibrium framework.

Finally, the two analyses reached somewhat different, although complementing conclusions as to the determinants changing the firm's optimal choice of organisational form. The result in the Lindbeck - Snower model was that a number of developments affect the relative returns to task integration and thus the attractiveness of restructuring into a holistic organisation: the nature of technical change, changes in information technologies, workers' skill levels, and their preferences towards the versatility of work. In the Greenan - Guellec model the firm's choice of organisational form depended on the size of its labour force, but the interrelatedness to economy-wide developments were shown in the general equilibrium framework. The model showed how the organisational form depends on the technological level of the economy depicted by the number of goods in the economy. The decentralised style becomes more efficient when the variety of goods is larger, because then the labour force dedicated to the production of each good is smaller. In addition, the growth rate of goods is higher in an economy with decentralised firm organisations.

All in all, the analysis in this thesis delineates and explains important developments in firm organisations. At least the author would find it interesting to investigate the topic further. Although the empirical examination of organisational change is likely to be demanding because of the lack of proper indicators for organisational change, the quantitative significance of different organisational practices would shed light on the topic. Moreover, research on changes in the labour markets would most likely benefit from the insights of theory on organisational change.

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