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Machine tool services and innovation

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Abstract

This working paper is represents a first step in a larger effort to analyse innovation and sourcing of mechanical technology in Norway. In particular it addresses innovation in machine tool (MT) system suppliers' organisations and how the sourcing processes emerge through interaction between users and suppliers. The Norwegian version of this kind of technology sourcing is influenced by the fact that there are no domestic manufacturers of MT technology. Sourcing of manufacturing technology is performed by a group of relatively small firms, importing and procuring MT and MT systems and user relevant knowledge intensive services around the products. We call them MT system suppliers. The MT system suppliers offer advanced portfolios of MT and MT systems and a high degree of service concerning installation, operation, maintenance and training. Our focus is based on empirical evidence mainly from sourcing situations between larger MT system suppliers and customers within machinery and equipment industries. Moreover we have focused on sourcing situations of relatively complex technical character, requiring high degree of customisation of the product-service delivered. The issues of this paper can be summarised as follows: How do MT system suppliers innovate? How can one describe the processes that take place between supplier and customer? What are the main functions of MT system suppliers?

MT system suppliers innovate mainly through the specific sourcing situations, by learning to produce services at higher quality. We describe how this influences MT system suppliers' product portfolios, service strategies and organisational configuration. Monitoring global technological innovation, knowledge accumulation and knowledge storage are core aspects for these firms' performance and competitiveness.

The study indicates that the sourcing situations are complex social interactive processes. Important interaction takes place in introductory phases of the investment, leading to strategic decisions concerning technical and organisational solutions. By far not all of the strategic decisions are absolute and irreversible. On the contrary uncertainty seems to characterise these interaction processes. Allocations may imply unintended results and many changes might even generate new problems and have unintended and costly consequences. Technology sourcing situations characterised by a high degree of customisation demonstrate that new technical problems, needs and functions are often defined during the process of customisation.

Norwegian MT system suppliers are in general capable of supplying up to date manufacturing technology to all industrial users within an average technological level. It is more difficult to supply the large complex MT systems that advanced users require, without the aid foreign competence. As MT systems get more complex technically, material handling systems turn out crucial for utilisation and efficiency. Material handling systems or robots are increasingly representing an integrated part of manufacturing technology. There seems to be a certain lack of domestic system supplier capability of supplying material handling systems.

Interaction takes form as network building around the customer, aiming at solving organisational and technical problems. Network actors are customers, suppliers, subcontractors, users of similar technology, manufacturers of MT technology etc., in general institutions and companies relevant for the sourcing project. Interaction implies continuing negotiation and flow of knowledge in a number of different forums.

Public policy should address global technological monitoring and strengthening the ties between education, research and technologically ‘average and low level' user firms. Contours of a vicious circle seem to become discernible, concerning educational aspects and low flow of personnel to such firms.

Keywords: Innovation; Machine tools; Networks; Services

Table of contents

Machine tool services and innovation

1. Introduction

This report addresses innovation processes in sourcing of mechanical technology in Norway, in particular how these processes emerge through interaction between user industry and suppliers of machine tool (MT) systems. The Norwegian version of this kind of technology sourcing is influenced by the fact that there are no domestic manufacturers of MT technology[1]. Sourcing of manufacturing technology is performed by a group of relatively small firms, importing and procuring MT and MT systems and user relevant knowledge intensive services around the products. We call them MT system suppliers. The MT system suppliers offer advanced portfolios of MT and MT systems and a high degree of service concerning installation, operation, maintenance and training. Our focus is based on empirical evidence mainly from sourcing situations between larger MT system suppliers and customers within machinery and equipment industries. Moreover we have focused on sourcing situations of relatively complex technical character, requiring high degree of customisation of the product-service delivered.

Although MT technology sourcing to customers most often includes a whole network of actors (MT system suppliers, foreign manufacturers of machine tools, business administrative, technical and organisational consultative firms, subcontractors, customers' customers etc.) our focus is mainly on innovation processes in and between the two institutions; the MT system supplier and its customer. This focus indicates that the institutional dimension in the sourcing of MT technology is only partly discussed. The study does not provide a picture of institutional dynamics between the whole system of technology agents for user industries in Norway.

Our definition of machine tools or machine tool systems includes units of production means for tooling and preparation (cutting, milling, boring, casting etc.) of materials (metals, wood, plastics etc.). A typical example would be a firm's production of valves for customers that utilise them in hydro energy production. Production involves every operation from the casted valve arrives in the factory. It is then milled, bored etc. and finally given surface treatment and finish. Machine tools, which perform these operations, come in stand-alone versions or in systems, e.g. two or more machine tools integrated through a robot or another material handling system. Moreover machine tools and machine tool systems

[1] International literature defines machine tool industry as production of larger units of production means for tooling and preparation (cutting, milling, boring etc.) of materials (metals, wood, plastics etc.) in manufacturing of goods. In for example, C. Edquist & S. Jacobsson, **Flexible Automation, The Global Diffusion of New Technology in the Engineering Industry**, (Basil Blackwell, 1988), or

E. Ehrnberg, **Technological Discontinuities and Industrial Dynamics,** (Chalmers University of Technology, 1996) p.51

have intangible as well as tangible components. This is basically the reason why this sector is interesting as a 'service' sector. Main services around the components include advisory and consulting functions in the important decision making processes leading to investment, installation, test-running, maintenance, basic training in operation of the tools and software installation and more advanced training. Hardly any machine tool or machine tool system comes without software components. Mostly due to innovation in MT technology, internal logistics or materials handling systems have become an integrated part of these technology sourcing processes.

We shall argue that innovation in this supplier-user context of technology sourcing typically takes form as medium and long-term processes of inter-active co-operation and organisational learning in direct connection to the planning, delivery and operation of the MT system. Flow of service is usually from service provider to customer, but flow of knowledge and learning, is often mutual. Customer preferences are crucial dimensions, in particular in sourcing of more advanced machine tool technology. But the picture is mixed due to a great heterogeneity in technological level among both MT system suppliers and customers. This observation has important implications for policy making on the area. Policy instruments have 'traditionally' focused on technology push activities, measures that in turn have revealed extensive users' needs for consultative management and business administration. Policy instruments that focus on users' different technological level seem more appropriate. From another perspective, MT system suppliers have limited product and service portfolios when it comes to advanced MT technology. This is in particular the case in an advanced sourcing context where customers see material handling and internal logistics as integrated parts of the investment. In such cases, monitoring of international innovations in MT technology and a network of foreign competence and suppliers are core elements if MT system suppliers are to perform successfully.

Data used in the study stems from a variety of sources. We have not been able to find any material covering this service sector in particular. There exists literature on user-producer interaction dynamics in the machine tool industry[2]. But we have not come over any work particularly focusing on this service sector's structure and performance. Research reports covering related areas have to some extent been informative, focusing on machine tool producer and user industries etc. However more important has been the general and more specific information from informal discussions with actors in the sector, on fairs and through interviews with system supplier and customers. All together this gathering of bits and pieces of information has resulted in the picture of core actors and what is going on in the sector. The more systematically gathered empirical data includes 5 case studies[3]. The case studies cover only what we consider the more complex sourcing processes, in other words customised relations with a

[2] For example Tryggestad in Carlsson 1995.

[3] Sources have been, on the supply side, two of the largest MT system suppliers in Norway, and on the demand side, three in a Norwegian context relatively large customers within manufacture of machinery and equipment. This limited empirical evidence has narrowed the scope of the study, specifically when it comes to describing sourcing situations of totally different service intensity.

high degree of supplier-customer interaction. It means that we have neglected 'simpler' sourcing processes with standardised stand-alone machine tools and a low degree of supplier-customer interaction.

The report is organised as follows. Section two gives a brief technical and historical overview of innovation in machine tool technology, innovation which significantly has shaped both the heterogeneity in user industries and the framework for the way MT system suppliers and their customers operate. Section three takes a closer look at the MT system suppliers as a sector and elaborates on their product/service portfolios, service strategies and organisation. Section four attempts to describe and discuss, on basis of a theoretical conceptual framework, interaction between MT service suppliers and customers as it emerges in our empirical material. Section five draws the report to a close by highlighting some policy issues and directions of further work.

2. Innovation in machine tool technology

Innovation in MT technology has during the last 20 years changed the environment totally in which MT system suppliers and mechanical engineering firms operate. Table 1 displays the general lines of innovation within MT technology.

Table 1. Technologies in the machine tool industry 1975-1990

Technologies in the machine tool industry 1975-1990

	Solid mechanics	Machine design (gearing)	Machine design (bearing)	Engineering materials	Control engineering a	Software engineering a	System engineering b	Computer communication b
Conv.lathe, 1975	X	X	X	X				
CNC lathe, 1975	X		X	X	X	X		
FMS, 1990	X		X	X	X	X	X	X

a) Includes knowledge of drivers, sensors and electronics
b) Application specific knowledge is a prerequisite for good system engineering
Source: From Paper 1a in Ehrnberg 1996, Technological Discontinuities and Industrial Dynamics.
Based on an interview with Professor Nils Mårtensson, Chalmers Univ. of Technology (July 1991)

According to this table there are two general complementing developments, on the one hand from stand-alone machine tools to machine tools in system (FMS), on the other hand from manual operated to numerically and computer controlled machine tools. The different effects of the technological innovations in MT technology and production techniques are anyway numerous, and have partly taken very complex forms, for example integrating electronics and mechanics (mechatronics). Software units of the machine tool are definitively important. As a parallel to developments in MT technology, advanced software systems concerning quality and competence management have emerged. Another crucial and often totally integrated feature of MT systems is the material handling, or internal logistics system. The lines of development have thus given potential to radical changes in all aspects of industrial production. Advanced computer controlled machine tools and machine tool systems can be applied in all operations, from raw material preparation to processing, quality control, and all of it linked with a computer controlled internal logistics system. 3 D modelling software is also

increasingly utilised in advanced firms for efficient component control and adjustment management. Investment and utilisation of MT in industrial production thus increasingly requires specific knowledge, not only when it comes to the operation of MT, but knowledge around material handling and the whole process and organisation of production.

Innovation in MT technology has definitively implied demand for specific skills and knowledge in MT procurers' organisations too. The need for a staff with advanced technical competence and skills is obvious, if we look at the staff development in most of the MT system suppliers' organisation. A bottleneck in staff management is caused by the difficulty to find staff with the combination of advanced technical competence and craft skills. Both system suppliers and their customers incidentally refer to the problems of facing a 'vacuum cleaned' labour market, and the problem of finding personnel with relatively high formal (if possible cross-disciplinary) technical competence and still willing to get their hands dirty.

Internal logistics and material handling have also increasingly emerged as significant integrated parts of machine tool technology. Many Norwegian system suppliers do offer material handling systems to their MT systems. However, the portfolio of material handling systems is often radically smaller than the portfolio of MT systems. Customers do not always find the right material handling system from the same system supplier. This might imply bottlenecks in the investment processes of customers that are especially in need of integrated automation.

As mentioned MT system suppliers do not touch on all aspects of manufacturing technology. MT system suppliers are only one group of technology sourcing actors for advanced manufacturing technology. The whole system of technology sourcing to mechanical engineering industries includes diverse actors such as hardware suppliers, software suppliers, private consultancies within production technique, logistics and quality management, and public and semi-public institutions. All in all they offer small and large hardware components - stand alone and in systems - robot systems, material handling/logistics systems, software components and organisational and business consultancy services. The public institutions are often engaged in skills formation and training of personnel.

As in other areas of rapid technological change, machine tool technology has experienced a great expansion in variety and complexity, due to integration of applications in information and communication technologies (ICT), electronics and material technologies into mechanical technologies. For the firms this has resulted in extremely expanded technological opportunities. Consequently, diffusion patterns vary, and this has implied a great heterogeneity in the context of both supply and demand of MT technology and related technologies.

3. The Norwegian MT system supplier sector

The Norwegian sector of system suppliers consists of 30-40 companies of varying size (average around 15 employees). Firm turnover differs significantly, from a few million NOK to between 100 and 200 million NOK. All together they ac-

count for an estimated total turnover of around NOK 1 billion (1994), half of which comes from larger machine tools[4]. The numbers of employees in these firms amounted to approximately 500 persons in 1994, including persons that are not employed directly in the procurement of MT.

Product portfolios of system suppliers have tangible as well as intangible components. Although the main product is machine tool hardware, hardly any machine tool or machine tool system comes without software components. Main services around the hardware components include installation, test-running, maintenance, and basic training in operation of the tools, in addition to software installation and training. This is the broad context within which MT system suppliers operate and innovate. The software part of the product is definitively very important. Installation of advanced manufacturing technology has to an increasing extent become dependent on computer and software control. But still is a significant share of the market stand-alone machine tools. Most of the system suppliers offer advanced services, either with internal competence or via co-operation links and partners. Some firms consider it important to be able to offer all service components in-house, while others choose to sub-contract widely. Thus companies are totally differently organised:

- They have different product portfolios,
- They have different service strategies,
- They have different organisational configurations.

In the following section patterns of innovation will be described according to these three key areas.

[4] Estimations are done by a representative for a central actor in the procurement of machine tools in Norway.

3.1 MT system suppliers' product portfolios

Firms in the sector have a great span in strategy when it comes to product portfolio and service intensity. We may distinguish between firms with a *product strategy* and firms with a *service strategy*.

Firms with a product strategy often have a relatively diversified product portfolio, spanning from clothing, hand tools and hobby articles to machine tools. These firms seem partly to ignore service aspects around MT, and the focus seems to be on selling products and not services. Basic installation and operation training may be offered, but maintenance service and more advanced training are often outsourced, if procured at all. Firms with this strategy tend to only procure simpler featured MT and in any case no MT systems. Anyway the product strategy obviously does not require the kind of specific competence as the other common strategy does, the service strategy.

Firms with a service strategy tend to have more focused product portfolios, e.g. on only larger, advanced MT and MT systems or on MT with specific properties. The service strategy integrates the concepts of product and service to unseparable units delivered to the customer. Close interaction between supplier and customer tends to start already with the first inquiring telephone call. The notion in these firms seems to be to sell services to the customer. There is full flexibility in degree of service and knowledge flow concerning advise, installation, operation, maintenance, training and wider aspects of production engineering.

Aspects connected to these diverse product portfolios may explain strategic differences concerning knowledge intensive services tied to deliveries of machine tools. Firms with a strategy concentrated on procuring only larger machine tools, tend to offer a more complete service, considered the customers' potential need for knowledge. However, there exist differences also within firms with strategies of delivering knowledge intensive services integrated with the machine tool; some firms limit their service to only the most necessary around physical aspects of the machine tool, for instance installation and test running.

Different product portfolios are basically matters of partnership and network between MT system suppliers and international MT manufacturers. Depending on MT manufacturers' strategies, agencies for procurement of a specific label are usually distributed to one or several system suppliers in a country. One of the most important functions that system suppliers need to handle properly, is the monitoring of global innovations in MT technology. As one of the key procurers and mentors of technological innovation to users, the system supplier stays competitive for customers only by thoroughly performing the monitoring function. The agency is a framework, in which monitoring processes may be relatively structured. The two partners, the MT manufacturer and the MT system supplier, have routines of updating each other on supply and demand changes. But the monitoring function must go beyond the established framework of pledged relations to well known MT manufacturers. System suppliers that have a strategy of being in the forefront of innovation in MT technology must continuously participate on international exhibitions and fairs and through other

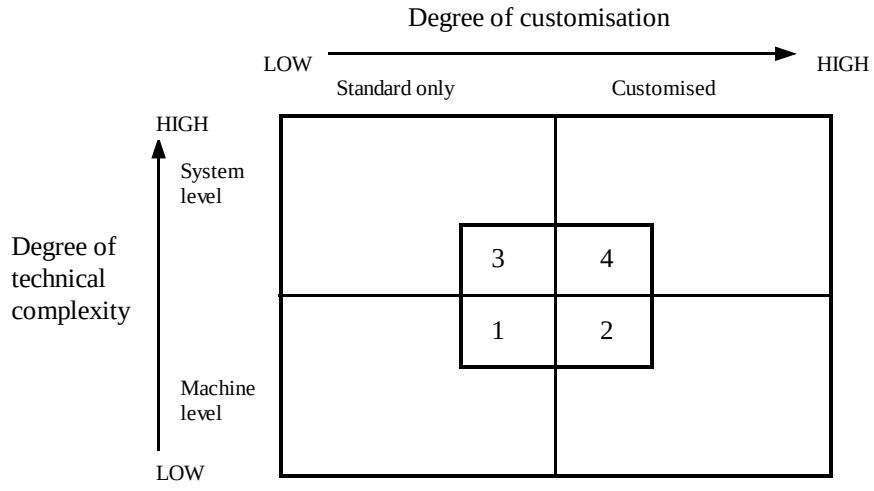
relevant media keep up with the latest developments. Hard competition and radical changes in world market shares during the latest two decades indicate shifts in leadership, both technologically and on cost. Sources within the field assess the challenge of performing the monitoring function well as an outmost important management tool for MT system suppliers. This is vital in order to stay competitive and be able to supply customers with up-to-date technology, at least on a medium and long term basis. Consequently, well performed technology monitoring costs money, mostly due to the fact that qualified personnel, travel expenses and networking are unavoidable costs.

Product portfolios of Norwegian MT system suppliers are strongly influenced by the structure and technological level of the user industries. We will not say much about the user industries here. We will only state that users make up an extremely heterogeneous group of firms, not only across different industries but also within the same industry. There is nothing negative in the fact that firms are on different technological levels of sophistication. There is still definitively a market for manual operated stand-alone machine tools, but in this study the empirical data is from relatively advanced machine tools and machine tool systems.

3.2 MT system suppliers service strategies

System suppliers' provision of services can be thought of as ranging from highly standardised to highly customised relationships between customer and supplier. This is a convenient conceptual framework for description and discussion of different aspects concerning service provision and organisation of system suppliers. Figure 1 below presents two dimensions of technology sourcing, one along technical complexity of components delivered, and the second along the characteristics of service delivered.

Figure 1. Two Dimensions of Technology Sourcing



Source: Tryggestad in Carlsson, 1995

Degrees of technical complexity represent the distinction between machine-level sourcing - the delivery of one numerically controlled stand alone machine tool

(NCMT) - and system-level sourcing - the delivery of a flexible manufacturing system (FMS) - consisting of several NCMTs integrated through material handling devices. Along the other axe the degree of customisation is viewed as from standardised to customised. The difference between a standardised and a customised pattern of technological innovation lies in the social context within which processes of service design take place. A high degree of customisation is thus present if the delivery of a MT or a MT system is subject to comprehensive services in addition to what can be considered basic services.

Viewed in light of our empirical data the dichotomy is not so clear. The span in technical complexity of the products and the degree of customisation offered by the system suppliers can be argued to be unique in every new sourcing context, depending on technical features of the MT system delivered and depending on customers' varying needs. Every new sourcing context is thus configured by customer needs and system supplier capability of delivering. In other words the social context is changing. Focusing on the supply side this is partly related to the size of the system supplier. Firm size (number of employees, turnover etc.) is definitively connected to capacity of delivery. It also relates to the MT service supplier's strategy when it comes to product portfolio, service intensity, subcontracting of service etc. Of the Norwegian 30-40 MT system suppliers there are only around 10 or 12 'larger' actors with only machine tools in their product portfolio. As mentioned earlier, several companies have diversified product portfolios and other products than machine tools account for a substantial share of turnover. At the end of the day the Norwegian market only has a handful of firms with total dedication to procurement of machine tools and in-house service capabilities. And these MT system suppliers seem to be the ones supplying advanced user industries.

3.3 MT system suppliers' organisations

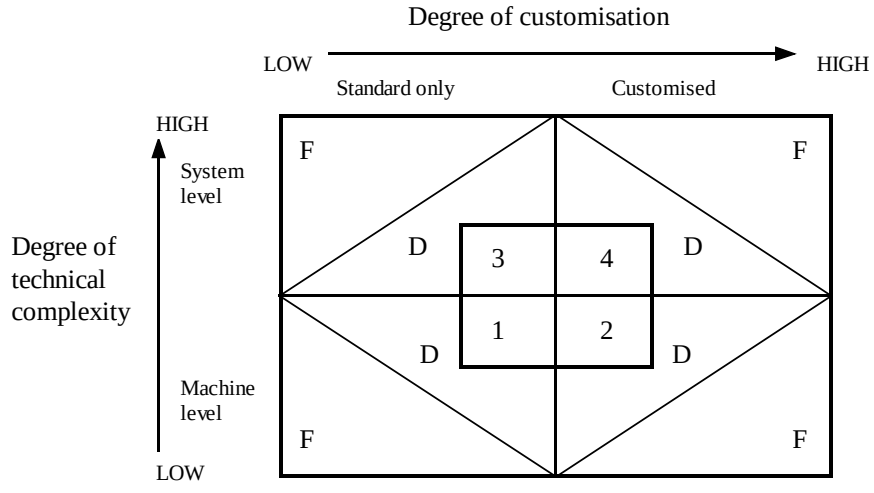
MT system suppliers' organisational configuration is above all interesting when it comes to organisation of product and service knowledge, in particular how they produce, store and transfer knowledge relevant for customers. MT system suppliers turn out to be differently organised, particularly when it comes to in-house knowledge and skill accumulation. Generally speaking we can observe two different strategies. Notice that this generalisation only applies to the largest MT system suppliers, all together not more than about six firms. Some firms have a strategy of developing specialised personnel, while other firms organise their work around generalists. The difference between a generalist and a specialist points broadly speaking to the installation of the hardware of the technology. On the one hand firms with specialists tend to separate personnel taking care of the more routine dominated procedures (installation, maintenance etc.) from personnel dealing with the more customised parts of services around the machine tool technology (advisory, functions, training etc.). On the other hand firms within the generalist strategy seem to want to develop each employee to be able to perform all kinds of functions in the sourcing process. In the relatively small organisations of Norwegian MT system suppliers, no particular strategy can be argued better or worse for the customer. The MT system supplier does most often in any case have to deliver the total package of services, either with in-house or sub-contracted competence.

It can however be argued that the different strategies are even more important for longer term in-house knowledge and experience accumulation. Information from the case studies reveals that MT system suppliers in general do not have systems that structure and codify experience and knowledge coming out of customer relations. The closest one gets to such systems are project files - mostly containing technical specifications of the delivered system - manuals and handbooks for specific MT systems. Other kinds of useful experience based knowledge from projects are stored as tacit knowledge in personnel. A couple of MT system suppliers claim to be working on systems of storing experience and knowledge for reuse purposes. In general MT system suppliers have not come far in processes of systemising and codifying important tacit dimensions of experience. A lot of this knowledge and experience is not easy or even possible to codify. Given the small number of employees in touch with these learning processes, MT system suppliers are vulnerable to even small changes in staff.

4. Customer – supplier interaction in practice

In the following section we return to the conceptual framework from paragraph 3.2 above. We shall add one dimension (illustrated in figure 2), namely the extent to which foreign actors dominate the sourcing process. Moreover we shall utilise the framework to describe and discuss empirical examples of customer-supplier interaction in sourcing of MT technology. As mentioned above, MT system suppliers' provision of services ranges from highly standardised to highly customised regarding relationships between customer and supplier. Figure 2 presents three dimensions of technology sourcing, the first along technical complexity of components delivered and the second along the characteristics of service delivered. The third dimension concerns whether domestic or foreign actors dominate in the sourcing process (in the figure D and F).

Figure 2 Three Dimensions of Technology Sourcing



Source: Tryggestad in Carlsson, 1995

The difference between a standardised and a customised pattern of innovation lies in the social context in which processes of service design take place. A firm

with a low degree of customisation shows no particular attention to even basic services delivered with a machine tool. A high degree of customisation is present if the delivery of a MT system is subject to comprehensive services in addition to what can be considered basic services. Within this three-dimensional context one may speak of four cases of supplier-customer interaction of technology sourcing, each of them dominated by domestic or foreign actors. Together there are eight:

- Machine-level sourcing in standardised relations, domestic or foreign dominance
- Machine-level sourcing in customised relations, domestic or foreign dominance
- System-level sourcing in standardised relations, domestic or foreign dominance
- System-level sourcing in customised relations, domestic or foreign dominance

The range of our empirical data limits our utilisation of the conceptual framework above. The system suppliers we have used as respondents belong to the small group of large suppliers that concentrate on offering advanced services and system-level machine tools. They are of course able to deliver machine tools of simpler complexity, but our case studies have focused on relatively large projects, at least in the Norwegian context. These large investments are delivered from MT system suppliers with what we would consider the service strategy. Less complex customer-supplier relations, like machine-level sourcing in standardised relations, may be seen as systematically present in sourcing processes of system suppliers with a so called product strategy. We have studied investment processes which definitively are characterised by customised relations; complex processes of interaction involving not only supplier and customer, but also involving the customer's customers and suppliers and users at different locations of the value chain. The case material may therefore not be considered exhaustive in the sense of giving a comprehensive view of dynamics in MT technology sourcing.

Moreover the conceptual framework used by Tryggestad is not perfectly adjusted to the Norwegian context. It takes departure in the Swedish context of technology sourcing, a context which is significantly larger than the Norwegian. Sweden has several large machine tool manufacturers and a large group of advanced users, particularly in the car industry. The Norwegian context is small and special. Norway has only a very limited number of advanced MT system suppliers, there are no domestic MT manufacturers, and the user market is small when it comes to demand for advanced manufacturing technology. Actors of supply and demand therefore quite early look to foreign competence in the sourcing process. The third dimension in the framework, domestic vs. foreign supply, is thus partly very relevant in our empirical material.

4.1 Machine-level sourcing in standardised vs. customised relations

Machine-level sourcing can be seen as the speciality of system suppliers with a product strategy. The delivery is characterised by low technical complexity in the function specified, e.g. a replacement purchase of a stand-alone NCMT. The more standardised the sourcing relation, the more dominating becomes the price aspect of the relation, Tryggestad argues (Tryggestad in Carlsson 1995). The customer-supplier relationship typically lacks innovative aspects for that reason. It involves at most incremental innovations as minor adjustments to customers' specifications, typically as replacement of outdated production means. Both advanced and less advanced users replace stand-alone machinery with the latest within stand-alone technology. However, advanced users demanding advanced manufacturing technology tend to stick with the already pledged relationship with MT system suppliers at their technological level. On the other side large, advanced users partly also seem to utilise the cost efficiency of system suppliers with product strategies, which are able to compete on price because they do not spend resources monitoring technology that intensively, pledging close relations with foreign manufacturers.

Customised relations within machine-level sourcing describe situations where customers demand specially-designed machines for specific applications that call for close interaction with suppliers. For an inexperienced customer most system suppliers would be of potential interest. And system suppliers with product strategies may be able to deliver certain customised features to competitive prices, although then often outsourced. Outsourcing of additional service functions is most often the strategy of these MT system suppliers. For experienced customers are usually only the advanced system suppliers the real option. The advanced (often largest) system suppliers offer in-house competence to all service functions. And they are definitively the ones with the most extended horizons when it comes to considering and advising MT technology and production technique in a more comprehensive perspective.

Breaking the barrier to another technological level
A couple of years after an investment in a stand-alone numerically controlled machine tool (NCMT), customer A assessed it reasonable and financial possible to go for a higher degree of automation within the production cell in question. The production cell machines different groups of relatively small valve components and the best material handling solution turned out to be a one-armed multi-task robot, after a process of consultation with MT system suppliers. The robot was delivered with standard features, but due to the complete lack of customer knowledge in this technology, two additional service packages, in addition to standard installation, test-running and maintenance, were necessary and demanded. These included training in programming and operation of the robot and integration with the NCMT. On basis of the upgrading to this technological level and the specific new software knowledge for programming and operation, the customer evidently broke a barrier of uncertainty in processes of new technology acquisition. New knowledge and extended technological horizons led in turn to further projects of investment in new technology in other production cells. Extended technological horizons did however not make knowledge intensive services from MT system suppliers in further projects obsolete. Customer A

did actually follow up the good experience of the first co-operation with the MT system supplier. A complete training package was necessary also in this project, due to the fact that relevant employees had to be brought into the learning process, and they had not been in touch with the first project.

Our empirical material on machine level technology sourcing seems to indicate persistent dominance of domestic institutions. It is reasonable to argue that domestic competence to a large extent is able to deal with sourcing of stand-alone machine tools.

4.2 System level sourcing in standardised vs. customised relations

According to Tryggestad system-level sourcing in standardised relations can be observed when customers purchase a MT system 'off the shelf' as a package consisting of components (e.g. a machining centre and a robot for material handling), selected to fit specific customer requirements, but no further design or development of available equipment is necessary. In particular this may be the case when the customer has knowledge of the similar MT system from previous investments. Advanced customers with very good technical competence and knowledge of own production processes may also invest on this kind of basis. Design and adjustments are then done with the customers' internal staff.

System-level sourcing in customised relations represents installation of machine tools of complex technical specifications, which requires close interaction with suppliers. In advance of the investment the customer often has no or only vague ideas about technical and financial aspects of the process. They may have a financial framework or financial limits, and they do definitively have current process and product specifications and a notion of wanted performance. But system investments of this kind often open up for many technological solutions, and the right decisions are only made on basis of the potentially complex process of information flow and co-operation between customer and supplier, and eventually other important actors, during the whole sourcing process. It is in these highly complex and customised situations that the process of technological innovation is assumed to be most dominant. It is therefore not surprising that an important part of the interaction takes place in strategic and preparatory activities of the investment.

Customer as technology monitor and idea generator in transnational technological systems

Customer B worked a year on preparatory management of an (by Norwegian measures relatively large, NOK 4 mill.) investment, concerning identification of core components, prioritising the components, decision on what kind of machining process to use and general specifications for best possible effect of the investment. Approaching the supply market it turned out impossible for Norwegian system suppliers (they were basically two competing) to supply the wanted material handling system to the MT system. The customer had found it technical feasible and essential to be able to process a daily demand of the 50 core components in the same MT system, and this decision made the material handling system to a core component of the investment. The Norwegian system suppliers had no idea about where to find the solution. Through its' network of

subcontractors and customers, customer B accidentally got the idea of looking to Finland, where both a manufacturer of material handling systems and some users turned out to be located. Another two months were spent to study these concepts of material handling, and through meetings and visits with the Finnish manufacturer and a Swedish user, and eventually the Norwegian MT system suppliers, a decision was made about system specificities. Customer B did not want a direct delivery from the foreign manufacturer, and the preferred Norwegian system supplier was therefore brought into the process on conditions as in any other investment in Norway. The system supplier joined the network and spent some time learning before the project was started and delivered as a 'turn-key' concept. The system suppler had experts from the Finnish manufacturer over during installation for advice and training.

Customer – supplier co-operation in the decision of machining concept specifications
In the same 'turn-key' investment, the decision concerning machining concept (basically whether to utilise lathe or milling principles) was made by customer B as an in-house preparatory process. They chose a milling machining centre, a result of detailed assessment of the components they were to machine. The decision on specifications of the milling machining centre was however made in close co-operation with the system suppliers. At that time in the process customer B had chosen two system suppliers from the ten initially bidding for the project. Customer B now spent a significant amount of time, browsing and searching for the 'right' machine tool solution, with significant contribution from the two remaining system suppliers. Joint visits to international fairs, machine tool manufacturers, and visits to users of similar technology, were arranged. As the specific MT system was picked in agreement with the system suppliers, customer B triggered the last competitive struggle between the two suppliers, focusing on and assessing service quality, contents and price aspects. The customer picked a system supplier that had already done some smaller deliveries. Service quality and contents etc. were the crucial issues, not the price.

System supplier adjustment of customer demand on basis of cost proportions
In another investment process, customer C wanted a fully automated machining centre running 24 hours in the time consuming machining of the heaviest components in their portfolio. After having established contact with the system supplier, which was one the customer had worked with earlier, the delivery turned out relatively easy to install. However internal logistics turned out as the crucial factor. The investment budget of customer C became decisive for the level of automation. The budget turned out too small. Total automation was too costly, mainly because of the large and heavy components to machine. A too large material handling system was required. A compromise was chosen, having one operator working during the day shift and the machining centre working unattended during the night shift.

System level sourcing is definitively more dependent on foreign competence. The basic reason for that is the fact that the small Norwegian context makes it almost impossible to stay totally updated on technological development. MT system suppliers can not be expected to have experience-based competence within

all areas of advanced manufacturing technology. Unfortunately the result of this is that solutions for customers sometimes seem solved in cases of coincident.

4.3 Different social settings of interaction

As we have seen the difference between a standardised and customised pattern of innovation lies in the social context in which processes of service design take place. Deliveries of standardised components seem to contain less social interaction, while customisation involves more interactive activities. The processes take different forms; telephone conferencing, regular meetings, visits, conferences, joint visits to fairs, joint visits to customers and other actors, formal courses (theoretical and/or practical), training sessions etc., and of course concrete purchases of relevant services in this network. We have indicated that interaction between supplier and customer may be relatively strong in introductory phases of the investment; preparatory information flow as a basis for major decisions. The interactivity consists of relatively intensive, engaging social processes leading towards concrete events. In other words there is continuing negotiation between the relevant actors going on, processes of problem solving leading to milestones in the project. Actual contribution from the different actors does definitively go beyond what is formally purchased. Moreover it is not easy measured and goes beyond the framework of this report. It depends on actors' knowledge and capabilities, and it depends on the perspective and the details of the case study data. The social processes have the definite aim of leading to the last phases of the investment, namely installation, test-running, training and finally maintenance routines and spare part supply.

As we get closer to the implementation phases of the investment, the processes consist of delivery of the more concrete service components, that is knowledge about how to program, operate and control the MT system. Often these learning processes are organised as soon as possible after the customer has made the decision of co-operating with that system supplier, before even the installation of the MT system has started. These phases are characterised by more defined division of labour between system supplier and customer, as standardised courses often are. Nevertheless many of these functions are relatively intensively interactive, often localised at the shop floor and with reference to specific features of the MT system. Interactive information flow is linked to specific conditions connected to design, adjustment and adaptation to the customers' individual needs. The needs depend on the physical and organisational framework, in which the installation is done.

A variety of training arenas

When customer B had made a decision on system supplier and type of MT system, a relatively long learning and training process started. Relevant personnel was very early brought into the process, participating in combined study and training tours to the machine tool manufacturer, to a couple of users, in addition to both theoretical and practical training at the customer plant. The Norwegian MT system supplier made all arrangements. The training process was running as the installation started, and the customer staff was able to follow the progression and finally with a reasonable good understanding of the new MT system go into the last practical training sessions.

Installation is in most cases a service function that is performed exclusively by MT system supplier personnel. The MT system supplier has got the full responsibility for a complete installation. The main reason for this is that most sourcing contracts have conditions of regular maintenance activity, in addition to spare part supply and emergency help in case the MT system stops. Customers do not usually have to care about maintenance services at all.

4.4 Organisation, programming and operational training

Organisational restructuring, whether reallocation of production cells or reorganisation within the cells in general, provokes system level investment. Organisational change often walks hand in hand with issues of programming and operational training in connection to an investment in MT technology. One can speak of two general features of organisational innovation in the reorganisation of production cells, mainly depending on the users' technological level. Knowledge and skills concerning software units and operation of the MT system are often either integrated in the production cell or segregated between the cell and a management level. In production cells with complete internal control, which is probably the most common way of organising control in Norwegian firms, it seems crucial to train personnel with a combined competence of mechanical craft and new software and programming capabilities. A common trend is that some of the personnel in the cell is made obsolete due to the automation of production, and remaining personnel is thus often required to master both programming as well as automatic and manual operation of the tools. Although skills and knowledge about the automatic production are crucial, traditional mechanical understanding, experience and skills are required as well. It is in particular this kind of personnel that is a scarce resource for companies within mechanical technologies. They might find persons with either automation skills and -knowledge or traditional mechanical craft, but finding persons with the combination of both these skills, is not easy.

In more advanced manufacturing systems, control over the production cell may be organised from a level above the cell, through a centralised management unit. This implies a more defined division of labour and more specialised competence.

Machine tool system investment triggering plant and personnel reorganisation
In connection to its investment in the relatively large flexible manufacturing system (FMS), customer B had prepared for organisational restructuring. However, as decisions concerning FMS specifications were made, it became evident that the whole production cell would require more physical space than expected. On basis of customer internal research and advise from the system supplier (provided through the earlier mentioned Finnish manufacturer), the solution to this structural problem was a total reallocation and reorganisation of literally all units of production and production cells. The investment thus triggered a strategic important restructuring of the whole factory.

5. Concluding remarks and policy issues

We have described certain features of innovation in MT system suppliers' organisations, and we have described interaction in the sourcing of machine tool technology, in the end leading to innovation in customers' production and organisation. Procurement of machine tool systems takes place as context specific co-operative activity in preparatory and implementing phases of the investment process.

Focus has been relatively strictly on machine tool system suppliers' interaction with their customers, though other actors, e.g. manufacturers and other users, have been pointed out as important. A striking feature in the market of MT technology is the heterogeneity. Each sourcing situation is a product of the specific context in which the services are delivered, typically shaped by the level of strategic and technical competence and capabilities, in the customers' organisation and in suppliers' and other actors' organisations. In the conceptual framework the contextual span and numerous potential situations are shaped by the three dimensions, degree of customisation, degree of technical complexity, and foreign vs. domestic supply. We have mainly described sourcing of machine tool technology along customised dimensions and a relatively high degree of technical complexity, and we have empirically indicated how evolving such processes can be. Indirect dependence on foreign competence is obvious. Manufacturers of machine tool systems are foreign firms. Direct 'investment specific' dependence on foreign competence is however also relatively obvious. Domestic institutions have no possibilities of staying up-to-date on global advanced manufacturing technology and related competence, especially not experience based competence. A lot of the sourcing processes of advanced machine tool systems are consequently unique to the domestic environment.

Sourcing of 'off the shelf' machine tools within standardised customer relations, e.g. replacement of an existing machine tool with an improved version, limits improvement potentials for customer to the component that is machined. Sourcing of MT systems of high technical complexity with a high degree of customisation opens up for more pervasive innovation, advocated by improvements in many chains of production through interaction and learning at the management, organisational as well as the technical level. It is along these characteristics of MT technology sourcing that technological innovation processes are most dominant, both for the customer and for the system supplier. By far not all of these improvements are intended, and many changes might even generate new problems and have unintended and costly consequences. Technology sourcing situations characterised by a high degree of customisation demonstrate that new technical problems, needs and functions are often defined during the process of customisation.

We have experienced that interaction between customer and supplier and evidently other actors, fills important functions in early phases of the investment, in particular concerning establishment of networks of competence, and early strategic technical and financial decision making. This is definitively not a mar-

ket where the customer on basis of internal assessment and needs approaches a clear context of suppliers, makes a decision and invests in the right MT system. This is in particular the case in sourcing situations characterised by technical complexity and customisation. In standardised and relatively simple sourcing situations the role of the MT system supplier in early phases seems to be less important. The first phases of investment are decisive because they concern the customers' (and suppliers') access to information about potential technological solutions and possibilities.

In other words this concerns technological monitoring. Although to a varying extent, customers are in general experts of their own production technique. They hold specifications of production performance and product features and they hold situation specific experience about component level properties and current performance limits of production. Demanding customers are therefore able to express demands concerning technical and performance features of the investment. It is however here customer capabilities seem to face its' first limit, especially if Norwegian system suppliers do not have any readymade notion of solutions, as we have shown in the empirical description above. We have pointed out how significant and important the performance of technological monitoring is for Norwegian MT systems suppliers who want to stay in the technological forefront. This is not easy (possible) for a single MT system supplier, even for the largest ones. The Norwegian market is small and the Norwegian MT system suppliers are small. MT system suppliers are probably fully able to supply less advanced parts of Norwegian user sectors. But as we comprehend the situation today, advanced customers themselves have to build ad hoc networks of technological competence in order to be able to plan, implement and succeed in an investment project.

Technological monitoring performed by private and public R&D environments should therefore be more linked with MT system suppliers, which represent activities closer to the user environment. Our impression concerning such co-operative links is mixed. MT system suppliers on their side argue that they are in the absolute forefront of the technological development. R&D institutions argue the same. Both parties are to some extent right. We have indicated that as demand for complexity in MT systems increases, system suppliers are not able to follow the development, and foreign actors have to be brought in often with considerable cost a time consuming activity. There exists co-operative activity between the large advanced industrial actors in Norway and certain R&D institutions. But co-operation between R&D institutions and the average small, medium sized, less advanced industrial customer is of very low intensity. Private R&D departments, mainly located in the large multinational enterprises, seem perfectly able to perform in accordance to in-house demand. But public educational and R&D institutions do not seem to fit that neatly into what we consider the core of customer demand in the area of renewal of MT technology. R&D institutions might well be in the forefront of the development, but then probably too far ahead compared to the needs of the average industrial customer. Only very few customers see for example 3D modelling as a appropriate tool when they still have some way to go updating their manual machine tool systems.

In the cases where domestic competence and capabilities within MT systems suppliers are able to supply most of the Norwegian demand, one bottleneck

seems important; the material handling system in particular for larger complex MT systems. Here the Norwegian industrial system does not have domestic manufacturers. And except from the domestic MT system suppliers, there is no obvious actor performing technological monitoring and mentoring functions with close relevance to user industries. Users have to seek foreign co-operation partners themselves, and for large companies this is probably no big problem. For smaller companies however, this function is crucial.

We have indicated that the technological system for MT technology is not restricted to Norway. Norwegian users do not and can not restrict their purchases to Norwegian suppliers. Still technology sourcing by Norwegian users of advanced manufacturing technology takes place mainly within a national rather than an international technological system, at least this is the conclusion we draw from our empirical data. Although foreign manufacturers contribute, domestic MT system suppliers are wanted as mentor, and responsible for implementation of the sourcing. The picture is however probably more mixed. Domestic users have the alternative of direct contact with foreign manufacturers or suppliers. We do not know to what extent this is the case. It is a subject for further investigation.

It is not easy to shape public policy instruments around technology that seems dependent on unique and ad-hoc shaped contexts of competence intensive networks of users and suppliers. Moreover additional aspects beyond technological questions seem as important; strategic decisions, organisational aspects, finance etc. The most important concern for public policy seems to be the lack of an actor performing comprehensive technology monitoring with links not only to advanced large user industries, but with strong ties to small and medium sized, less advanced firms. MT system suppliers perform this function to some extent, but the technology monitoring task requires far too many resources than the performance of a single system.

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Cfr. footnotes in the text.

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STEP gruppen

STEP-gruppen ble etablert i 1991 for å forsyne beslutningstakere med forskning knyttet til alle sider ved innovasjon og teknologisk endring, med særlig vekt på forholdet mellom innovasjon, økonomisk vekst og de samfunnsmessige omgivelser. Basis for gruppens arbeid er erkjennelsen av at utviklingen innen vitenskap og teknologi er fundamental for økonomisk vekst. Det gjenstår likevel mange uløste problemer omkring hvordan prosessen med vitenskapelig og teknologisk endring forløper, og hvordan denne prosessen får samfunnsmessige og økonomiske konsekvenser. Forståelse av denne prosessen er av stor betydning for utformingen og iverksettelsen av forsknings-, teknologi- og innovasjonspolitikken. Forskningen i STEP-gruppen er derfor sentrert omkring historiske, økonomiske, sosiologiske og organisatoriske spørsmål som er relevante for de brede feltene innovasjonspolitikk og økonomisk vekst.

The STEP-group was established in 1991 to support policy-makers with research on all aspects of innovation and technological change, with particular emphasis on the relationships between innovation, economic growth and the social context. The basis of the group's work is the recognition that science, technology and innovation are fundamental to economic growth; yet there remain many unresolved problems about how the processes of scientific and technological change actually occur, and about how they have social and economic impacts. Resolving such problems is central to the formation and implementation of science, technology and innovation policy. The research of the STEP group centres on historical, economic, social and organisational issues relevant for broad fields of innovation policy and economic growth.