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Exploiting the Control Revolution

Uncertainty Reduction, Value Creation and Appropriation

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Exploiting the Control Revolution:

Uncertainty reduction, value creation and appropriation in the division of labour

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Abstract

Much recent strategy literature argues that manufacturing firms should move downstream in the value chain to deliver complementary services to allow them to remain competitive and to grow. Many firms are investing heavily in product innovations while simultaneously shifting their position in the value chain. This paper attempts to explain why, under certain circumstances, product innovations and services are dynamically interdependent by creating a model that shows how uncertainty reduction and improved control can lead to the creation of economic value. As appropriation is distinct from value creation, firms change their means of appropriation accordingly. Empirically, the paper illuminates this phenomenon by analyzing how multinational corporations renew their product offerings by incorporating control technologies into their traditional mechanical engineering products. The paper suggests that entrepreneurial action and uncertainty reduction, a la Frank Knight, and economies of throughput need to be combined to explain why firms invest in product innovations to create value to appropriate returns by means of services.

1. Introduction

Much of the literature on firm strategy has analyzed the scope and the direction of firms' boundary changes. Chandler (1962, 1990) showed how in the 20th century large vertically integrated firms emerged to dominate a range of sectors, often by vertically integrating backwards, insourcing the supply of inputs to their production. Their growth was achieved through scale and scope economies in the physical processing of materials. These Chandlerian companies relied on in-house research and development (R&D) activities to create superior products, and their dominant market positions to provide barriers to competition (Chandler, 1990).

By the end of the 20th century, vertical integration had largely been abandoned in favour of firm specialization. This was the consequence of the expansion in global end markets, allowing for increased division and co-specialization of labour among firms. Large firms de-integrated vertically by outsourcing their upstream requirements for various inputs (Young, 1928; Davies, 2004). This meant that leading firms increasingly relied upon their core or distinctive capabilities, rather than the ability to perform all productive tasks in-house in the manner of the Chandlerian firm (Penrose, 1959; Richardson, 1972).

The recent business strategy literature argues that manufacturing firms need to rethink their strategies to create competitive advantage and increase their revenue streams by providing 'integrated solutions'. These can be viewed as complementary bundles of services and products that address customers' or users' business needs (e.g. Quinn, 1992; Slywotzki, 1996; Davies, 2003, 2004). Based on their core competences in manufacturing, suppliers are moving downstream to expand their offerings by providing additional distributional, operational, financial and maintenance services through the entire product life cycle (Wise and Baumgartner, 1999; Davies, 2004). By taking over service activities that previously were handled in-house by their customers or by creating new downstream services, suppliers are moving down the value chain[1] (Davies, 2004). This is a shift in the trend away from increased specialization to an emphasis on integration. Compared to Chandler's (1990) analysis the main direction is vertically downstream rather than upstream (although the latter may also occur).

The literature provides many explanations for why manufacturing firms move downstream into service offerings. Many products face a stagnant product demand and combined with increasingly strong global competition this decreases the margins on product sales so that delivery of complete customer-focused solutions has become important for competitiveness (Slywotzky, 1996; Wise and Baumgartner, 1999; Davies, 2004). Services can be attractive for manufacturing firms because many service transactions tend to be distributed over time and can provide firms with income from an installed base of products long after the initial sale. At the same time manufacturing firms are well positioned to carry out downstream activities because of their access to complementary assets (Teece, 1986). Finally, on average services tend to have higher margins than product manufacturing and require fewer capital assets.

It could be assumed that it has become *relatively* less important for manufacturing firms to concentrate on physical products and more important to deliver complementary services that satisfy customer needs (Quinn *et al.*, 1990; Wise and Baumgartner, 1999; Davies, 2004). However, this issue requires some consideration. Firstly, a new type of firm, the system integrator, has emerged (Prencipe *et al.*, 2003 (eds.); Davies, 2004; Hobday *et al.*, 2005). These firms focus on the design and integration of components and subsystems while relying on supply chains or markets to assure the acquisition of necessary inputs. Thus, the emergence of systems integrators has created a qualitative change, which explains the repositioning of some firms along the value chain.

Secondly, investment in product R&D has not decreased as many companies spend significant financial resources on product innovations. Many of these innovations are upgraded versions of antecedent products and, partly as a consequence of these innovative efforts, firms are diversifying the technology and knowledge bases of existing products (Granstrand *et al.*, 1997). Indeed, to retain sales and profits from products, investments in product developments are often necessary even for mature applications.

We will show that the abovementioned reasons for new business opportunities residing in moving downstream along the value chain in the form of supply of complementary services overlooks an important empirical phenomenon in that there can be *dynamic* interdependences among product innovations and services. Dynamic interdependences refers here to temporary mutual dependence of products and services for firms (e.g. Antonelli, 2001) to create and appropriate economic value. This notion stands in sharp contrast to bundling and integrated solutions, which refer respectively to combined sales of products, and products and services as single packages (Adams and Yellen, 1976;

Davies, 2003, 2004). Instead, dynamic interdependencies refer to the fact that appropriation of returns from services may be temporarily dependent on the ability of firms to deliver increasingly advanced products, and vice versa.

This paper will explain why product innovations and changes in services may be dynamically interdependent. To do this, we need to demonstrate these dependences empirically, but, more importantly from a theoretical perspective, we need to explain why there is such dependence. The explanation of why services and product innovations may be dynamically interdependent is based on how firms act entrepreneurially to the business opportunities inherent in the reduction of uncertainty. This reduction in uncertainty may lead to the creation of economic value, but in general the means of creating value do not solve the appropriation problem faced by innovators. In general, there is a division of labour among firms such that value created by one firm may diffuse to other firms or consumers (Levin *et al.*, 1987). Thus, in line with recent theorizing in the strategy literature, the role of division of labour among firms, and the distinction between value creation and value appropriation need to be made explicit.

To analyze how firms reduce uncertainty and appropriate returns we analyze the case of two multinational corporations (MNCs) renewing their offerings in the sludge dewatering, and compressed air businesses respectively, by increasing control over the applications encompassing their products. Traditionally, the capabilities of suppliers in these fields are based on mechanical engineering skills. This paper analyses how firms integrate information and communication technologies (ICTs) into their products, which gives rise to the provision of new services through augmentation of their product offerings.[2] ICT integration here refers to when firms integrate ICT components or sub-systems into products, which make the products more 'intelligent'. In both cases studied here the ICT technologies can be classified as control technologies, a class of technologies that significantly improves allocation of system traffic and reduces costs in operation (Nightingale *et al.*, 2003). This increased 'intelligence' of the products reduces uncertainty during operation, which translates into creation of economic value for the operator.

The paper is organized as follows. Section 2 discusses some aspects of how reduction of uncertainty is related to 'economies of throughput' and increased control, especially control technologies. It reviews how uncertainty reduction can be linked to new business opportunities and the distinction between value creation and appropriation under a division of labour. Section 3 outlines the case study approach while Section 4 analyses how two mechanical engineering MNCs have reformulated their product offerings by providing integrated ICT. Section 5 discusses the findings and, based on the notions of uncertainty reduction, value creation and value appropriation, outlines a model that explains why services may depend upon products, and vice versa.

2. Literature

Changes in control either in firms or in the economic system are mainly related to organization (e.g. routines), institutions (e.g. legislation or rules of the game) or technology (Beniger, 1986; Nelson, 1994; Nelson and Sampat, 2001). Changes in these dimensions alter the problems and opportunities that firms and other organizations act upon and how they coordinate their activities. Such changes may in turn lead to the creation of economic value or reduced costs.

Changes in control are linked to firm activities in the sense that increased control leads to reduced uncertainty. Uncertainty plays a core role in much of the literature as it is considered to be a barrier to entrepreneurial action (Knight, 1921; McMullen and Shepherd, 2006).[3] Entrepreneurial action characterizes firms that identify and act upon a novel business opportunity. These actions allow novelties be 'inserted' in the economic system and thus regenerate competition.

Entrepreneurial action can be understood as the "behaviour in response to a judgmental decision under uncertainty experienced in the decision of whether to act" (McMullen and Shepherd, 2006, p. 134). Such profit oriented actions are characterized by uncertainty as in some manner they are novel to the firm. Knight (1921) characterized entrepreneurial action as dependent upon the *reduction* of uncertainty. He explains the division of labour among firms by identifying and analyzing the role of general principles that reduce uncertainty. In particular, Knight found that firms and other organizations can reduce uncertainty by grouping and consolidating similar events, activities or objects. This allows variations in weather, the physical attributes of inputs into manufacturing or operations, and the timing of demand to be 'smoothed out'. The grouping and consolidation of single events or instances also lies behind the division of labour among different types of firms or between producers and consumers, as firms can specialize and improve the management of uncertainty.

However, uncertainty can never be fully eliminated; in entrepreneurial activities, by definition, involve firms in some uncertainty. Firms may also create uncertainty by changing the competition, for example, by innovating. Thus, a defining feature of entrepreneurial action is that it simultaneously reduces and creates uncertainty. Also, the basis for the grouping or consolidation – the combination of the production or delivery of similar objects – can be flawed from a cognitive, physical, economic or social perspective. Thus, Knight (1921) defined one type of actor, the entrepreneur, who takes on the responsibility for this residual uncertainty and as a reward keeps (potential) profits. Other actors (firms, employees, consumers, etc.) expect to be able to rely on the provision of particular physical and other economic goods (including wages) from these entrepreneurs, for a price.

There are two aspects that are important here. First, the grouping of similar instances leads to increased control, which in turn can, and does, lead to reductions in uncertainty. The economies of throughput literature has made important advances in explaining these processes. Second, identification of new business opportunities based on uncertainty reduction may imply a latent economic value that firms may act upon. However, the means for appropriating this economic value often do not coincide with the means for creating the economic value when there is a division of labour. This leads to the problem of appropriation. We discuss these two aspects below.

First, the economies of throughput literature relates to how fixed costs of capital investments are spread over a larger amount of output during a specified period of time, resulting in lower unit costs (Chandler, 1990, 1992; Nightingale *et al.*, 2003). More generally, grouping and consolidation, or what today we often refer to as learning and changes in scale and scope, lead to reductions in the marginal costs of production and higher profits.

Chandler (1962, 1990) focused on the physical processing of materials and showed how improvements in throughput could improve capacity utilization, resulting in economies of scale and scope of production where cost advantages were realized from high throughput. Thus, the major means of appropriation was the increases in throughput that resulted in economies of scale and scope. In industries such as oil, rubber, machinery, chemicals, industrial power and urban transportation, throughput determined profit. The higher the throughput, the greater the rate of return, meaning that up to some potential capacity the cost per unit fell with increased throughput while it rose if throughput decreased (Chandler, 1992).

Chandler analyzed cases where the manufacturer cut its own costs by achieving economies of scope and scale, resulting in higher profits *if* effective capacity utilization was assured and the market could absorb the products. The former allowed these firms to appropriate returns on their investments while the latter created economic value. The 'Chandlerian firm' grew by being able to match its product and service offerings to some characteristics (from the perspective of the products or services) of a large numbers of homogenous buyers or consumers. These firms became prime movers as they could increase their throughput to create economic value that they captured from investments in production facilities and managerial competencies to fully exploit the cost advantages of economies of scale and scope. Thus, companies grew by investing in new production technologies to exploit economies of scale, and by utilizing their resources better to exploit economies of scope at the same time as they spread their costs widely (Penrose, 1959; Chandler, 1990).

However, such growth changes the nature of the managerial and technological problems (Penrose, 1959). For example, when companies continued to grow they became largely dependent on techniques for monitoring and coordinating different operations to sustain their throughput. The uncertainty and the complexity grew beyond the scope of what individual managers could handle. Consequently, companies needed to adopt bureaucratic administrative processes for monitoring the behaviour of their current operations and the allocation of resources for future operations. Therefore, companies needed trained managers to monitor the flow of goods through the company, which in turn began to affect the organizational structure of these companies (Chandler, 1990, 1992). Techniques for monitoring and coordinating the processes within companies co-evolved with production technology, which allowed throughput to increase and materials to be spread across product lines (Chandler, 1990; Davies, 1996). The ability to control generated economies of scale, scope and speed[4] and made it possible for firms to continue to grow (Chandler, 1990).

However, when control techniques lag behind increases in the size and complexity of technology systems and operations, the ability to coordinate systems and operations is lost (Chandler and Daems, 1979; Nightingale *et al.*, 2003) resulting in what Beniger (1986) calls a crisis of control. Control is defined as 'purposive influence toward a predetermined goal' where the goal is directed and has to involve a continual comparison between current states and future goals (Beniger, 1986, p. 6).[5] The crisis or lack of control comes from expansions in scale and scope which increase complexity and consequently create uncertainty. Therefore, it is argued that lack of control can limit and slow down economies of scale, scope and speed (Chandler, 1990).[6] However, these obstacles to cost reductions create a locus for new control systems and control innovations in order to reimpose control (Hughes, 1983; Beniger, 1986). Beniger emphasized, like Chandler, the organizational side of control in order to increase capacity utilization or throughput (Beniger, 1986). The successive advances in control Beniger termed the control revolution.

This organizational focus has recently been complemented by literature that highlights the role of control *technologies*. Davies (1996) argues that a new concept of control is needed to explain cost reductions stemming from improvements in controlling the routing of traffic in a technical system by utilizing its actual installed capacity. The concept of throughput to explain economies of scale and scope as a driver of growth and the cost advantages from expanding the size and range of a system, fails to explain the mechanism for controlling a technical system that has interrelated components organized into separate subsystems, such as air traffic control in air transportation, or signaling systems in railway networks (Davies, 1996).[7] New control technologies used for controlling and coordinating subsystems can increase the performance of a technical system, giving rise to reductions in the costs of operating the entire system (Davies, 1996). These types of technical control systems allow new types of production economies, with a shift from the role of monitoring and organizational coordination to a critical role in the actual delivery of goods and services (Nightingale and Poll, 2000).

Based on Davies (1996), Nightingale *et al.* (2003) analyze and address the recent incorporation of software-intensive control technologies that significantly improve the allocation of system traffic and, by so doing, increase throughput and performance. They argue that innovations in control can increase the utilization of a fixed amount of installed capacity even when the scale, scope and speed are constant, without influencing the range of products (Nightingale *et al.*, 2003).[8]

Second, we argue that entrepreneurs can identify and act upon opportunities that are resident in the economies of throughput logic discussed above. For firms, the creation of value and the appropriation of economic value are crucial issues. Enabling customers to increase their throughput to reduce the costs of operation may provide a business opportunity for the manufacturers (suppliers). This cost reduction may be reflected in the creation of economic value (Chesbrough and Rosenbloom, 2002). However, the creation of value through reduced operations costs is not the same as appropriating economic value from the sales of technological (or organizational) advances.

The Chandlerian firms could appropriate economic value because they had built in protection barriers in their physical and distributional assets, such as the size of their production plants. Yet, it is not generally true that it is the manufacturer or innovator that receives a cost advantage from a product innovation and thus readily appropriates the returns from the innovation. Indeed, often cost reductions benefit the buyer or operator of the physical goods regardless of whether or not the manufacturer of the physical goods cut its costs through economies of scale and scope. Chesbrough and Rosenbloom (2002) emphasize that companies do (and should) focus on the user's or customer's need and how to *appropriate* economic value from satisfying these needs.

The body of literature that deals with how to appropriate returns from technological innovations focuses on how a firm can protect its innovation. The setting consists of analyzing how some given value is distributed among an innovator and competitors. This literature does not deal time with value creation. At the same time, there is some attention paid to the issue of how value is shared between the innovator and its customer, thus the literature is founded on principle of the division of labour.

Among the methods of appropriating returns patents have been a major focus (see e.g. Rivette and Kline, 2000; Arora *et al.*, 2001), and they, in theory, confer perfect appropriability. Thus, the emphasis has been on protecting an innovation from imitation, rather than the actual process appropriating value from it. For example, Teece (1986) proposed a framework for appropriating value from an innovation. This framework deals with how to appropriate value by building in protection barriers in different forms. Teece argues that intellectual property rights (IPR) is the primary means of appropriating value from an innovation and that an inability to protect an innovation with tight IPR protection speaks to the need to secure a position in complementary assets. Teece's framework, therefore, is focused on how to protect an innovation in order to appropriate economic value by excluding others from getting a share (Moran and Ghosal, 1999; Jacobides *et al.*, 2006). However, patents have been shown not to be entirely effective as competitors can quite easily invent around patented innovations (Levin *et al.*, 1987 Harabi, 1995). Lead times, sales and learning curve effects are more effective than the legal protection provided by patents for appropriating economic value. These means of appropriation are more in line with capturing or leveraging from the created value than with mere protection.

By leveraging on a new technology value has to be created in the first place, and if there is an economic value this often needs to be distributed between the manufacturer and the user, something that is largely neglected in the value chain literature. Hence, generally, there is a discrepancy between appropriating the economic value of the entrepreneur who bore the uncertainty while innovating, compared to the creation of the economic value that benefits the operator. To solve this, the entrepreneur may thus need to change position along the value chain and consequently its business model in order to appropriate economic value from the reduced costs for operators. The issue of appropriating economic value by increasing the throughput in customer processes with the help of new control technology systems has not been addressed explicitly in the literature, but would seem to have important implications for firm strategy.

3. Methodology

This paper builds on two explorative case studies (Eisenhardt, 1989; Yin, 1994) to explain why services depend on products, and vice versa. We analyze how mechanical engineering manufacturing firms reduce their customers' (the operators) costs by decreasing uncertainty through increasing control in the operations/processes, and how they try to appropriate value from the reduced costs received by the customers.

These two cases were chosen first because they reflect the general phenomenon of huge investments in product innovation accompanied by the move into services to appropriate financial returns. More specifically, the cases are characterized by increased control, which results in great economic benefits for operators (users). The evidence suggests that ICT-integration plays a fundamental role in how control improves the performance and functionality of mechanical products. At the same time, finding new sources of revenues is an important issue for firms producing otherwise mature products and this is also reflected in the way that the firms increasingly try to create competitive advantage by providing integrated solutions downstream. Second, the cases were chosen because the user situation is characterized by true Knightian uncertainty.

Although uncertainty and uncertainty reduction are pervasive, the two case studies are distinct in how uncertainty reduction takes place. This is important in that the paper aims to better capture the role of uncertainty and entrepreneurial action in relation to the recent strategy literature focusing on downstream moves in the value chain to provide a theoretical explanation of the dynamic interdependence between products and services. More specifically, the user applications of the case studies involve distinctive uncertainties because of the impossibility of a deliberately designed throughput for the operators of the machine in terms of inputs. This also means that the nature of *outputs* is uncertain *unless* the operators can reduce this uncertainty during operation. This differentiates the applications described here from, for example, machine tools such as lathes and milling machines, which have well-defined inputs and consequently the nature of outputs can more readily be controlled.

Case studies are superior for creating an understanding of empirical phenomena and for generating novel theory (Eisenhardt, 1989). However, case studies are inherently limited in terms of their generalizability (Yin, 1994). To some extent this limitation is reduced in that the cases are not focused on a specific sector or technology, but are linked to the phenomena of control technology and integrated solutions in the established literature presented in *Industrial and Corporate Change;* on control technology (e.g. Nightingale and Poll, 2000; Nightingale *et al.*, 2003) and integrated solutions (Davies, 2004). One of the products (compressors) is mass-produced, which may indicate that innovation in control systems is not just important in 'a specific set of sectors based around complex, large-scale production and distribution systems or networks' as claimed by Nightingale *et* *al.* (2003, p. 478), but may be of practical relevance in other types of technology-based systems.

The two case studies have some major similarities (even though they are based on completely different application areas) in respect of the reason for the introduction of centralized control systems (both for the innovating firm and for their customers) and the need to change the business model to appropriate economic returns and the difficulties that this involved. These similarities should lead to a more sophisticated understanding of the cases examined (Eisenhardt, 1989) and the role of control systems for mechanical engineering manufacturing companies. To reconcile the evidence across the two cases and types of data, and between existing literature and theory, the paper proposes a new theoretical vision. This is achieved by triangulating different data sources (Jick, 1979) and undertaking an iterative process between theory and evidence, starting from a loose set of ideas and frameworks from the existing theory. However, because of the limited number of firms analyzed, this paper should be seen only as a continuation of Nightingale *et al.* (2003) on the under-researched role of control systems, and as a first tentative step in understanding the large economic potential and business opportunities of control systems in customer applications.

With the help of colleagues we followed the business development processes for three and one and half years respectively, before and/or after the launch of the various versions of control systems in the firms. By doing so we alleviated exaggerated post-hoc rationalization of the actions taken by the firms and increased the possibilities of identifying the business opportunities of control systems. The data are based on internal presentations, workshops and seminars to identify viable business models from the new systems. Archival analysis was made on different business plans, annual reports and trade press. These data were complemented by in-depth interviews with managers at a variety of hierarchical levels and functional positions to obtain both a retrospective and prospective view on the new businesses based on the introduction of new control systems. Managers were asked to describe the reasons why the control systems were developed and the perceived business opportunities and challenges after doing so, from a technical, strategic, commercial and organizational perspective. The semi-structured interviews lasted 1.5–3 hours, and were recorded and transcribed. To validate the data and results of the study a draft of this paper was circulated to the firms' managers who had been interviewed.

4. Case studies

4.1 Alfa Laval

The first case study investigates and explores how Alfa Laval, a Swedish MNC increased data throughput and control for customers running wastewater treatment plants, which reduced uncertainty and consequently allowed customers to run more optimized processes for sludge dewatering.

Wastewater treatment plants treat effluent water and recycle clean (safe) water to watercourses. Alfa Laval manufactures decanter centrifuges designed to dewater sludge. The decanter centrifuges are used in the last step in the wastewater plant operations.

Sludge dewatering is the most cost-intensive process in a wastewater plant, representing some 35 per cent of total operating costs. A substantial part of the associated cost of sludge dewatering is the disposal of the sludge. Normally the dewatered sludge is transported by truck or rail to sites where a charge is made for disposal of the dewatered sludge. The less water there is in the dewatered sludge, the less costly it is to dispose of as the amount and the weight of the sludge decreases.

Sludge dewatering involves a high degree of uncertainty because the quality and density of the feed is unpredictable. Thus the operation of sludge dewatering requires a high degree of attention to run efficiently. To decrease the amount of water in the sludge, it needs to be dosed with polymers before being fed to the decanter. Without continuous attention, the polymer dosing will not be correctly adjusted to the sludge in the decanter operation, which will result in fluctuating performance processes, high polymer consumption, lower dewatered sludge in the cake, and a dirtier centrate, and may even cause breakdowns. When an experienced operator controls the dewatering process, the decanter will run at around 70–80 per cent of the machine’s potential. Without human surveillance, which is usually outside normal working hours, the operation has to be switched to safe mode to ensure that the process will not break down. This results in low performance and a sub-optimal process. Thus, the process reverts to lower performance whenever an operator is not controlling it. To achieve the greatest efficiency it is necessary for there to be three shifts of highly experienced operators on the dewatering decanters. However, even experienced operators cannot produce optimum performance from the decanter because of the complexity and uncertainty of the feed.

For decades, Alfa Laval has been the market leader in sludge treatment technology and has some 40 per cent of the world market (2005). During recent years, the product segment has been characterized by low profit margins because of the difficulty of differentiating the increasingly commoditized products. The decanter technology was invented around 1930 and the main principle has not changed. Firms innovate incrementally, usually by making smaller, higher capacity decanters. Over the years Alfa Laval has come up with new product generations that have provided the company with temporary higher margins. However, competitors quickly catch up which lowers Alfa Laval's profit margins.

Due to the complexity of the dewatering process, the only way to improve the process is to increase the control over the process to ensure a more efficient throughput. Beniger (1986) characterized these types of processes as a two-way interaction between controller (here, the decanter) and controlled (here, the sludge) by communicating back information through a feedback mechanism.

During the early 1990s, Alfa Laval had created a strong base of application knowledge in the form of knowledge about customer processes. However, this application knowledge did not result in products that were superior to those of its competitors. By adding ICT components and sub-systems to its decanters, the company sought to 'productify' that knowledge. These changes should increase the control of the sludge dewatering process and reduce uncertainty in its customers' operations. In particular, Alfa Laval recognized that ICT would enable a substantial increase in the amount, speed and quality of information between the controller and the controlled (the sludge going in to the decanter and the output from the decanter) and achieve a closer match between actual and intended output by measuring and modifying the input. Based on this improved information, the operator would have increased control for instance in terms of the amount of polymers used. At the same time the new technology would increase accuracy allowing more precise control and decreasing the likelihood of catastrophic failure in the process. It would also increase the speed of control in shifting it from an operator initiating action towards real-time control which would improve the match between potential and actual performance. It would increase the scope of control in progressing from local control of interdependent components to central control, which would allow for nearer optimal performance, and increased reliability of control allowing the firm to move from reactive to proactive maintenance. Alfa Laval identified and acted upon the business opportunity represented by lack of control in the customer process; it increased the capacity utilization of the installed base in sludge dewatering by developing a tailor-made automatic "optimization" control system.

It took 12 years to develop the control system from initial formulation to the first commercial sales. The idea to develop a control system that could change actual output came from an Alfa Laval engineer who, in 1991, had started to develop a control system. The company had gone a long with development, but encountered insurmountable problems related to continuous measurement of the characteristics in the sludge; it was unable to get a quality assured signal from the sludge. In particular, development was hampered by the poor performance of the technologies, especially the sensors, available on the market. Thus the project was shelved after a couple of years. The project restarted in 1999 when the improved performance of sensors allowed the sludge to be measured more accurately.

In 2003 Alfa Laval launched a self-optimising system (Octopus) for sludge dewatering. Octopus could monitor, analyse and adjust the process parameters (torque and differential from decanter, polymer dosing, concentration and quality of sludge) in realtime in the dewatering process and optimise the process for any process condition and needed no human supervision. The system could operate at near peak performance and optimise the dewatering process in terms of overall costs, solids recovery or cake dryness, depending on the customer’s priorities, regardless of changes in the feed conditions.

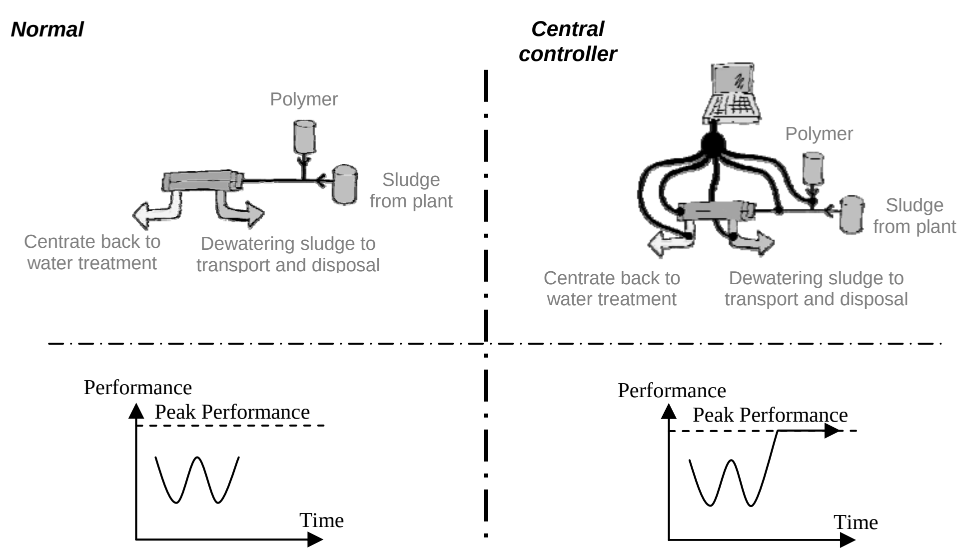

Figure 1 Performances of dewatering processes

Octopus can be classed as a dewatering autopilot with optimization features, enabling the dewatering processes to operate at a much higher performance than an experienced operator.[9] Octopus could reduce operating costs in the dewatering process by up to 20 per cent, which corresponds to a saving of 7 per cent in total plant operating costs.

The control system consisted of a computer, sensors with a control box, and cables connecting the sensors and the computer to the feed pump, polymer pump and the decanter. The sensors collected the data in real-time from the dewatering process and transmitted it to the computer, which allowed a feedback mechanism to modify inputs to optimize outputs. Octopus was based on a company specific software, unique to the industry, that represented more than four decades of Alfa Laval process knowledge and experience in decanter performance in dewatering applications, and which determined the new control settings. All process parameters were logged in history files, enabling the customer to analyze performance over time, and giving Alfa Laval unique insights into the customers' processes since it received all the data from the decanters. If any parameters were incorrect, Alfa Laval could adjust them from its headquarters. This facility is used to update systems when new software releases become available.

Alfa Laval saw Octopus as a real opportunity to reap some revenue from its knowledge and a way that the company could differentiate itself from competitors who did not possess a control system that would cut customers' costs. However, although increased control would reduce uncertainty and become an economic value in the form of reduced costs for customers, Alfa Laval could not see how it could be used to appropriate revenues unless it changed its business model fundamentally. That is, the company needed to find a way to capture returns from the economic value received by its customers.

Alfa Laval sold its products through capital sales. However, it realized that it would be difficult to get payment for the increased customer value. The company's market unit which sold the decanters, wanted to sell a package consisting of decanters equipped with the new control system (Octopus), through capital sales, in line with the traditional business model. However, this view was not only a matter of firm specific tradition. Decanters were mostly sold through public tenders, and seldom direct to end users, which basically inhibits other forms of revenue models than capital sales. In public tenders Alfa Laval was forced to comply with certain specifications, and if customers did not understand the advantages of Octopus, there would be no call for them. To sell Octopus with the decanters through capital sales would probably have resulted in the returns that potentially would arise from the increased customer value could not be appropriated.

The economic value to the customer in the form of annual cost savings for customers, based on the increased control and reduced uncertainty, were worth substantially more than the cost of a decanter during its life-cycle.[10] Even in the first year the savings that customers could make had a potential to amount more than the cost of the equipment. Savings would continue but would have no economic value for Alfa Laval. To appropriate this amount and retain the same business model would have meant radically raising the price of the decanters. This was judged by the management team to not be feasible as the decanter market was price focused. It was estimated that the new, higher priced product would only have low market diffusion as it would represent a major investment for the customer. This perception was reinforced as Alfa Laval frequently had lost sales of decanters when customers applied a capital cost evaluation, even though they argued that a total life-cycle cost would give a different result.

In 2002 Alfa Laval decided to adopt an annual licence fee model (service contract), based on the customers' cost savings, to capture value from Octopus despite the fact that this was a dramatic change in how Alfa Laval had been conducting its business. This change towards new services should reduce buyer resistance as the service contract would become an operational rather than an investment cost for the customer; the licence could be cancelled if the customer was not satisfied; and it could be more easily related to savings. The licence fee would qualify customers for free updates of software since customers paid for uptime (therefore maintenance and support were included). Having customers with different versions was considered to be a problem if Octopus had to be maintained and would probably have resulted in loss of reputation for Alfa Laval if customers purchased Octopus without the services to handle break downs, etc. Given that this was an entirely new way of doing business, Alfa Laval's management team decided to create a separate business unit to develop the new business services. These changes allowed Alfa Laval to offer its customers an attractive value proposition and enabled it to appropriate a large portion of the customer savings and achieve counter cyclical revenues with a gross margin of over 80 per cent.

4.2 Beta[11]

The second case analyses Beta's introduction of a centralized control system for compressed air installations, which reduced customers' energy costs by improving the utilization of installed capacity, and increased reliability and productivity through process surveillance. Compressed air plays a vital role in many industries, including manufacturing. A substantial part, around 30 per cent,[12] of the energy consumption in industry is from compressors (Source Newsletter, 2003). Compressed air is used as a source of power or as active air in industrial processes and, consequently, compressors are used in a wide range of applications. With the recent increases in the costs of energy, savings in electricity consumption have become increasingly important in many industries.

Compressors typically have a local compressor control. This control ensures that the compressor operates within a fixed pressure range to deliver a volume of air, which varies according to demand (Office of Industrial Technologies, 1998). In many uses, this demand is uncertain, and cannot be known prior to actual operation. When the pressure reaches a predetermined level the compressor unloads (and the pressure decreases) and when the pressure drops to a predetermined lower level the compressor loads (and the pressure increases). The range between these two pressure levels is the compressor's set-point, which determines when the compressor should load and unload. Local control works well in situations where a company has a single compressor and steady demand. However, most companies have a multiple compressor installation, and they add compressors as demand for compressed air increases. When there is a series of compressors that are running the load and unload of pressure of the compressors need to be offset in order to prevent the compressors from starting simultaneously. This way of connecting compressors is known as cascading and is the traditional way of handling increases in demand.[13] The combined capacity of the compressors at minimum has to meet the maximum air demand so that a multiple compressor installation operating by cascading needs to work at a higher pressure than a single standalone compressor, in order to meet maximum air demand. As demand for compressed air in companies varies over time, demand cannot be predicted, and since compressors do not operate at full-load all of the time, cascading becomes a problem in that it limits the ability to closely match demand for air, and creates a large pressure band. The result is that a lot of energy is wasted. At the same time it creates an unstable pressure, with shoots and undershoots of pressure that may negatively affect customers' business operations.

Compressor technology has been a core business of Beta for 100 years and since the 1930s the company has been the world market leader both technologically and in terms of market share. Given its long history the company had a large installed base of compressors, which it wanted to protect and also to increase its revenues from. During the 1980s and 1990s the mature compressor business had increasingly been characterized by fierce competition and lowering profit margins added to which customers rarely replaced their compressors. In principle, with proper maintenance compressors can run indefinitely but 10-15 years is considered to be the normal economic life span, usually because of the higher efficiency of new compressors. Thus, innovations in the compressed air industry have largely been based on advances in technology, where Beta has been a major actor. However, although these new innovations were considered by Beta to compete, these products did not substantially increase its revenues.

For users of compressed air, the energy costs are by the far largest expense during the compressor's life-cycle (Office of Industrial Technologies, 1998). Typically, energy consumption represents around 70 per cent of the overall compressed air system life cycle costs, whereas the capital investment is only some 20 per cent and maintenance 10 per cent. During the 1990s, Beta realized that if the company could lower energy costs, customers would save a tremendous amount of money over the compressor's life-cycle. This signified a change in problem perception as the compressor manufacturers had been focused on their manufacturing capabilities; now they had to think about coordinating compressor installations more efficiently. By offering the best life-cycle cost based on reduced energy consumption Beta saw that it would get a competitive edge. The abandonment of a product focus in favour of a move to the provision of complete solutions for compressed air installation would enable the company earn more money from its installed base as well as new customers. As described by the interviewees, the key was to reduce the customer's uncertainty by increasing the control over the process.

There had always been a need for control systems in compressed air installations, but this had increased over the years and had been rater overlooked as compressed air installations become increasingly more complex, and different types of compressors were introduced with varying demand, and increased size of installations, air capacity and in energy intensity. In the 1990s Beta introduced some new types of compressors (turbo and variable speed drive compressors) that needed better control in order to achieve efficient capacity utilization and to avoid blowing-off energy. Given that each compressor type had its own specific energy versus flow characteristic and widely varying optimum operating zone, efficient capacity utilization of multitude compressor installations was impossible to achieve without increasing control in real-time operation. This development led to a 'crisis of control' (Beniger, 1986) where local control was becoming a highly inefficient way of running multiple compressor installations. If control was left to local compressor controllers in multiple compressor installations with no centralized coordination working in real-time, optimum utilization of compressors was impossible to achieve. Central control systems were needed to monitor, compare and modify inputs and outputs in order to get a tight pressure band and match capacity with demand. This presented an opportunity for Beta to re-establish and increase control in compressed air installations, and turn centralized control and reduced uncertainty into cost reductions for customers.

Having identified a need amongst its customers, i.e. to save energy, and recognized an opportunity to generate more rents through a more integrated solution for compressed air installations, in 1999 Beta started development of a centralized control system. This system would allow automatic selection of the optimum mix of compressors either by installed power or by technology, allowing a reduction in the required working pressure through a signal (pressure sensing) and increased control through control from one centralized point rather than at every individual compressor. What the control would do would be to take over from the local compressor controllers and work with one common set-point rather than with one set-point for every compressor. The control would allow selection in real-time of the most energy efficient and optimal compressor mix and their operating points. The idea was to optimize the running of the compressors to allow the users to match demand as closely as possible to the compressor output. The control system had to be clever enough to select which compressors needed to be run, and to stabilize and lower the pressure to the lowest possible point (see Figure 2).

This would enable new types of services to be offered to customers. Central controllers for compressed air installations, where data from each compressor could be received and processed, facilitated remote monitoring of compressed air processes. This would increase reliability and up-time resulting in fewer production interruptions, increase efficiency resulting in reduced operational costs, and facilitate access to valuable data for compressed air installations. The development was initiated in 1999 as an extension of the development to provide customers with central controllers; the device was connected to the central controller on one side and to an Internet connected machine on the other side. This allowed both Beta and the user to monitor all the machines and the compressed air process remotely and allowed Beta to collect and store data from user's compressed air installations, which was valuable information that could be used for other purposes. Real-time information could be visualized and automatic warnings could be notified via email or SMS. Therefore, monitoring of data, storage of data and a feedback mechanism of the process became an externality from which Beta could continue to build services. Beta was able to start services on demand rather than having services based on timed intervals, and having compressor overview, data mining, etc. tied to service contracts.

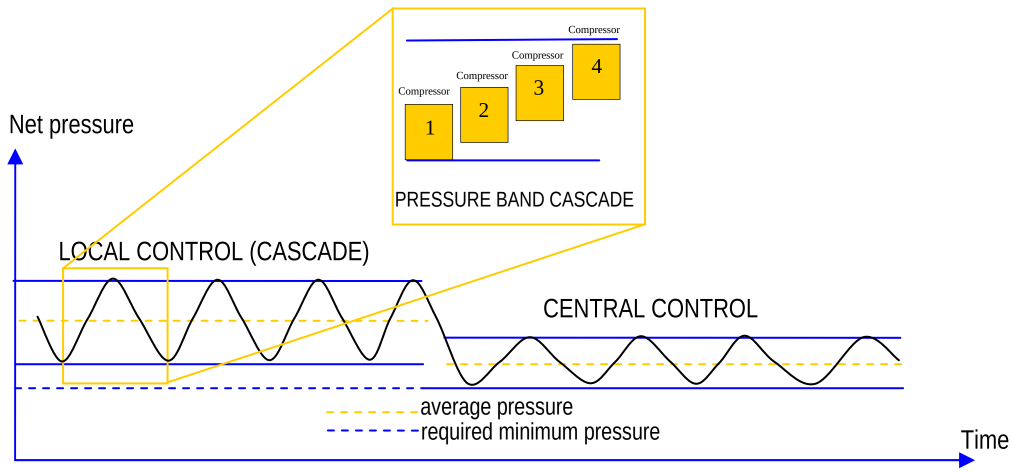

Figure 2 Local control vs centralized control

The development of the advanced centralized controller was made possible by integrating ICTs into the compressed air installation. The control system consists of hardware and software. The hardware in the control system consists of an industrial computer, a monitor and a controller area network which links all local compressor controllers to the centralized controller unit which is a computer and resembles a closed box. However, similar to the decanter control system, it is the software in the computer which is the key to the control system. The software comprises algorithms of how compressors work and operate, with reaction times, flow and energy characteristics, and control logic for starting, stopping, unloading and loading compressors to keep the pressure in the user-defined pressure band, and to make decisions about which compressors need to be run. Interviewees claimed that these algorithms are based on Beta's deep manufacturing competencies and are highly specific to the company.

For Beta the reason for taking control over the customer's compressor installation was to earn more money from the installed base. This was to be achieved by reducing the users' costs and uncertainty through increasing the control of compressor installations, and by appropriating a part of that economic value. However, there were problems with the development of the control system and with appropriating a fair share of the savings the customer would get by using the centralized control system. Basically, Beta did not succeed in getting the right architecture for the revenues.

When Beta launched its centralized control system in 2002 it was not the only company in the market selling systems for coordinating compressors. Compressor manufacturers and control companies had started to sell basic control systems based on sequencing. Sequencers, as the name implies, changes the sequence of the compressors. In its simplest form sequencing is user-defined, and determines start up and shut down depending on the time of day and the day of the week. The sequences override the compressors' local controllers resulting in a tight pressure band. On the other hand sequencers cannot coordinate the choice of compressors and can only coordinate limited number and different types of compressors. Control systems based on sequencing therefore only control net pressure; the energy savings that result are not as great as those obtained if compressors are optimized to provide more timely matching of inputs to outputs. Compressor installations that are complex systems with multiple compressors and varying demand, require more sophisticated control systems. Beta was the only company that was able to offer such a system.

Customer savings of about 10 per cent were possible from Beta's control system. For the customer this economic value was more than the cost of the equipment during its projected life-cycle (15 years). Because other companies were selling control systems through capital sales, Beta realized it would have to do the same. It began to market its sophisticated control system for a very small price compared to what the customer would save. By 2003, it realized that this was not bringing in revenue to the company and it introduced a licence (which also included maintenance and upgrades) based on what customers would save, which allowed the company to appropriate a larger part of the customer savings. However, few customers were interested in taking out a contract because Beta was not demonstrating to them how much money or energy they would save. The customer wanted to see what it was paying for and found it difficult to believe that Beta's system would save more energy than the controllers from competitors; they told Beta representatives that the financial viability of the new system needed to be demonstrated.

Within its current business model, Beta was not able to appropriate what it deemed to be a reasonable share of customer savings. Beta outlayed substantially more than the amount generated by sales of the control system between 1999 and 2005. Beta tried to appropriate returns through a fixed or variable fee based contract based on what customers would save, but because they were unable to convince customers of how much money and energy they would save, this was not successful. Beta decided that to differentiate its offering it should develop the control further and make potential savings more tangible. This decision was based on the presumption that they had a better solution than their competitors, which would reduce electricity consumption to a greater extent. They believed that they could achieve repeat revenues by providing the control system as a service contract rather than a one-off sale, thereby appropriating a larger part of the customer saving and establishing a highly profitable business. In 2005 Beta began development of a new generation of centralized control systems.[14]

5. Discussion and Conclusion

The starting point for this paper was a simple empirical observation; if there are such good reasons – as indeed there are – for established manufacturing firms to move down the value chain and to supply services, why do so many firms continue also to invest so much in product R&D? Section 1 showed that there are a number of 'obvious' reasons including the fact that products and services may be complementary. However, in some cases there is more to the relationship between products and services than mere complementarity and we argue that the reason for this is not made explicit in the strategy literature dealing with moves along the value chain. This paper aimed to explain the dynamic interdependence between product innovations and services through theoretically oriented case study research.

Section 4 examined the cases of two multinational suppliers - in the sludge dewatering and compressed air business – who successfully integrated ICTs into their traditional product offerings. In both cases it is clear that the companies made the investments to create economic value. For Chandlerian firm economic value was achieved through cost cutting. In our case the cost cutting was based on the operation of the capital goods.

Given that there is a division of labour among co-specialized firms (this paper focuses on suppliers and operators/users), within traditional business models, the economic value benefits operators throughout the entire product life time. For suppliers, however, appropriation of these cost savings is not directly related to the creation of economic value. This highlights that, in general, when there is a division of labour, there is a discrepancy between the creation of economic value and the appropriation of economic value by the supplier. Whilst this is hardly a new finding (e.g. Chesbrough and Rosenbloom, 2002), it is the basis for our explanation of the dynamic interdependence that exists between product innovations and services and especially in the two companies we studied. So how can we explain the dynamic interdependence in the two case studies?

From Knight's perspective, entrepreneurs are the actors that take on uncertainty in return for a (potential) profit. His analysis is based on how uncertainty can be reduced and become the foundation for entrepreneurial profits. Section 2 presented Knight's arguments about entrepreneurs both bearing and creating uncertainty through their entrepreneurial actions and also, by identifying and acting on business or innovative opportunities, reduce uncertainty. This is illustrated in box (1) in Figure 3.

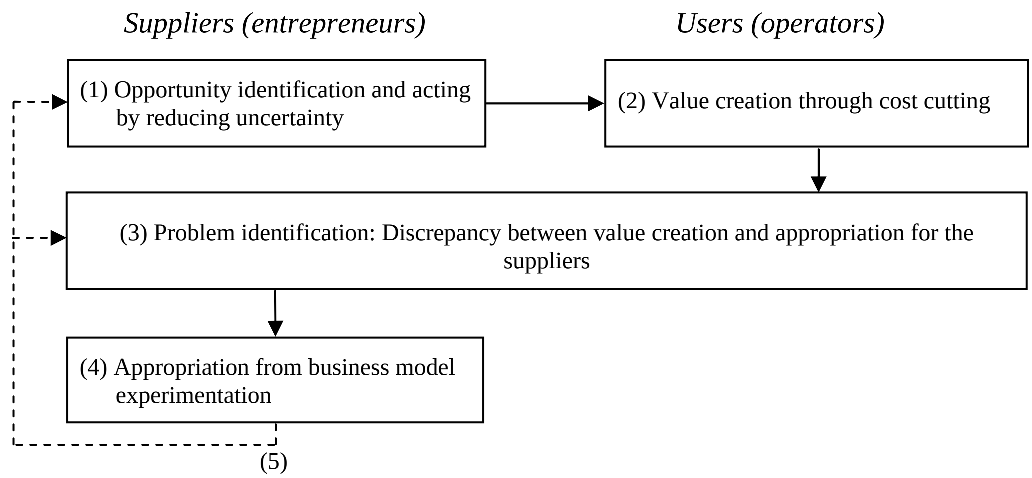

Figure 3 Uncertainty reduction, value creation and appropriation in two case studies

The two case studies showed how the companies identified and acted upon opportunities to reduce uncertainty in the operation of their products through integrating ICT into their products (i.e. by creating centralized control systems for interrelated components and processes). These entrepreneurial actions meant that the two firms carried and created uncertainty as, from a technological, organizational, commercial and financial point of view, the outcomes were unknown. The business opportunities lay in the fact that the investments made by the firms were explicitly addressed to managing the uncertainty by increasing the control of the operators. The input to the sludge dewatering and compressed air operations was uncertain in that it is beyond the capabilities of the operators to control (or design) it. However, the ICT-based control systems greatly decreased the uncertainty of operations. The new control systems were able to control the processes such that required output was achieved with less energy and therefore at lower cost. Thus, the decrease in uncertainty was related to both cost savings and quality improvements, as the operator had greater control over operations (see box (2) in Figure 3).[15]

The companies' innovative efforts and resulting software based control systems, were based on a combination of ICT solutions and accumulated ('traditional') experience in mechanical engineering manufacturing and knowledge about their customers' application processes. The customers' cost savings came from improved control, which allowed for increased throughput confirming Beniger's (1986) argument that new control can shift the boundaries where bottlenecks in a technical system come into play.

Thus, we find that investments in product improvements are linked to value creation via reduction in uncertainty which in turn leads to cost reductions for the operator. However, as shown in box (3) in Figure 3, from the perspective of the producers or entrepreneurs this is unrewarding as value creation is distinct from appropriation of economic value (Moran and Ghoshal, 1999; Amit and Zott, 2001; Chesbrough and Rosenbloom, 2002; Jacobides *et al.*, 2006). In general terms, this can be understood as a process of problem identification which is determined by the difference between what something is and what something could be from the perspective of some actor (Pounds 1969). The cases highlight the problems involved in appropriating economic value from the reduced costs for operators within the producers' current business models. Box (4) shows that firms identify a need to change their business models, from selling the products to providing services under contracts, to appropriate returns from the creation of economic value.

As shown in box (5) in Figure 3, there are feedback loops within the system. Three major types consist of (a) the identification of new business opportunities based on uncertainty reduction, i.e. some opportunity recognition followed by entrepreneurial action, (b) internal learning or customer response, and (c) actions of competitors that change the competitive landscape. How frequently, and when and why firms move in the model is not explained by this approach. However, as discussed in Section 4.2, Beta changed its business model as a result of feedback by adding services to its product, and, by changing the technology, is planning to shift to provision of services only.

From the perspective of our proposed model and the two cases examined, products and services are dynamically interdependent because creation of improved products is linked more clearly to the creation of economic value, while the creation of new business models related to services, is linked to appropriation of economic returns. This is a simplification as there is generally not a one to one mapping between product advances and value creation, and services and economic value appropriation; it is a particularity of the case studies chosen. The sources of value creation and economic value appropriation will vary and we should not expect them to neatly come together.

This model should be valid for other control technologies as we would expect the logic to be similar, i.e. that product innovations improve control in some types of products (e.g. Nightingale *et al.* 2003). However, two areas warrant further research. One is that this study indicates that there are temporary interdependences among the novelties of products and changes in the business models, leading to changes in the services of the firms. Little research has been done on this topic. The second is that while there are limits to what we can say in terms of the relation between value creation, appropriation, and products and services based on our case studies, from a theoretical perspective there may be a valid explanation. The core notions that explain the dynamic interdependence between services and product innovations are (A) uncertainty bearing and entrepreneurial action, (B) uncertainty reduction, (C) creation of economic value, (D) appropriation. The theoretical foundations are uncertainty and entrepreneurship as outlined by Frank Knight (1921), which explains what entrepreneurs are and what they do, the throughput literature, which explains why and how companies become dominant through appropriating returns by means of economies of scale and scope (Clark, 1923; Chandler, 1962, 1990; Nightingale *et al.*, 2003), and the value chain and business model literature, which explains changes in specialization and the role of appropriation (Chesbrough and Rosenbloom, 2002; Davies, 2004). To demonstrate or dispute the relevance of the model proposed in this paper, further research will be needed, and particularly theoretical and empirical research to reconcile Knight's vision of entrepreneurial action with the economies of throughput and the appropriation literature.

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[1] For the purpose of this paper we do not make any distinction between value chain and value stream. These concepts refer to how firm specialization and what activities a firm handle in relation to other firms. This stands in sharp contrast to Porter (1985) who dealt with the value chain within the firm.

[2] This should not be confused with 'technology integration' (e.g. Iansiti, 1997), which refers to a particular mode of product development rather than to the nature of products, which is the present focus.

[3] There are many definitions of entrepreneurship: e.g. 1) entrepreneurs as bearers of irreducible uncertainty to make a profit (Knight, 1921), 2) specific actors that 'take' innovations and expand the business around innovations (Schumpeter, 1934, 1942), and 3) individuals or small alert companies or new ventures that react to various forms of market opportunities (Kirzner, 1973; Gartner, 1985). Each of these definitions characterizes entrepreneurs as acting under uncertainty. For our purpose the Knightian view is most relevant because of its emphasis on the act of reducing uncertainty.

[4] Chandler (1990) incorporates economies of speed into economies of scale.

[5] In that respect, there has to be a simultaneous comparison of inputs to goals where a two way interaction between controller and controlled has to occur by communicating back the results with a feedback mechanism that guides future action.

[6] The first large technology system where control was needed to be re-established was for railway networks. Chandler (1992, 264) meant that 'unless the movement of trains and the flow of goods were carefully monitored and coordinated, accidents occurred, lives were lost and goods moved slowly and with uncertainty'. Before control systems were introduced for railway networks, control problems produced diseconomies of scale where the operating costs increased with size (Beniger, 1986). This meant that companies could improve their scale and scope until they reached operational dead ends and where control had to be re-established in order to shift the limits of scale and scope upwards.

[7] In many circumstances there are problems to know the traffic or the actual load ex-ante and in order to use technical systems more efficiently and reduce costs, improvements and innovative efforts are needed to increase the control and the utilization of installed capacity.

[8] Thus, by optimizing performance over interdependent components software-based control systems have the potential to increase accuracy, speed, scope and reliability of control, and can overcome control constraints related to the complexity in a technical system, increase the internal speed and better coordinate

the routing and scheduling of system traffic in a technical system and potentially reduce costs (Nightingale *et al.*, 2003).

[9] According to Alfa Laval, Octopus gives a drier cake (typically 1–2 per cent) with the result of cheaper transport and disposal (up to 20 per cent savings), cleaner centrate and therefore lower processing costs (up to 98 per cent recovery), reduced polymer consumption (up to 30 per cent savings), greater flexibility in resource allocation and a more stable process resulting in less down time and minimum servicing compared to Alfa Laval's other products.

[10] Estimations show that the cost saving in operation over a year could be five times as much as the cost of buying a decanter. These estimates were made before the control system was launched, but have been found to hold true.

[11] The name of the corporation has been disguised for reasons of confidentiality.

[12] It is estimated that it takes about 6 kW to generate 1 kW of compressed air (Source, Newsletter 2003).

[13] In this way, each compressor gets its own delta so all compressors can run throughout their range. This means that if e.g. there are 4 compressors, the lowest set-point becomes 6.5 bar whereas the maximum set-point goes up to 8.5 bar, significantly increasing the pressure band (see Figure 2). Hence, even if the customer requirement is 6.5 bar (because that is the lowest set-point) the maximum set-point is determined by the operation of the equipment and in this case exceeds what is required, meaning that the installed capacity has to be greater than the actual requirement.

[14] What is new about the development and what the company is currently working on is an off-line simulator that is based on a model of how compressors work at a certain pressure, by running a simulation of the air net under local control to see what would happen if a centralized control system did not control the compressor installation and by comparing the simulation with the actual process and displaying the savings on a screen. When this is in place Beta will stop selling its advanced controller through capital sales and sell under a contract (or licence), either on a fixed monthly fee or based on what the customer ctual will actually save, which will allow them to take a larger part of the customer savings. The sequencer will be sold through capital sales because the competitors have similar systems, but will be used as a step in offer where the customer can upgrade the software to allow them to save more energy and to be able to control more advanced compressor installations.

[15] The identification of the business opportunities for Alfa Laval and Beta was directly connected both to the means of cutting the costs of operation for the customers and to appropriating a part of these cost savings in order to pay for the control systems. In the case of Alfa Laval this cost saving for customers was achieved through water reduction in the dewatered sludge, reduced polymer consumption and reduced human resources needs, and for Beta it was achieved in terms of reducing energy costs by coordinating the pressure of compressors.