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Exploiting the control revolution by means of digitalization: value creation, value capture, and downstream movements

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Abstract

This article explains why firms move downstream to profit from the value they create for customers through improved control. Under certain circumstances, product innovations and services are dynamically interdependent in the sense of improved control creating value for the customer. Since value capture is distinct from value creation, firms may need to change their means of appropriation to profit. Empirically, the article analyses how firms can renew their product offerings by incorporating control technologies into their traditional mechanical engineering products. In contrast to a strand in the recent strategy literature that argues that manufacturing firms should move downstream to deliver complementary services, this article explains these shifts as related to increased control, economies of throughput, value creation, and value capture. The article contributes to the throughput and control technology literature by showing the importance of differentiating value creation from value capture. The increased control by means of digitalization and the discrepancy between value creation and value capture explains why many manufacturing firms will become service firms.

JEL classification: L11, L23, L25, M13

1. Introduction

Based on their core competences in manufacturing, many suppliers are moving downstream to expand their offerings by providing additional distributional, operational, financial, and maintenance services over the entire product life cycle (Wise and Baumgartner, 1999; Davies, 2004). They achieve this by taking on the service activities that previously were handled by customers in-house, or by creating new downstream services (Davies, 2004). Many manufacturing companies that move down the value chain perform better than firms that remain upstream (Wise and Baumgartner, 1999).

The literature provides many explanations for why manufacturing firms move downstream into service offerings, including stagnating product demand and access to complementary assets making manufacturing companies well placed to conduct downstream activities (Teece, 1986; Slywotzky, 1996; Wise and Baumgartner, 1999; Davies, 2004). It might 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, the issue requires further consideration.

First, the emergence of systems integrators, that is, firms that focus on the design and integration of components and subsystems while relying on supply chains or markets to assure the acquisition of necessary inputs, constitutes a qualitative change, which explains the repositioning of some firms along the value chain (Prencipe *et al.*, 2003; Davies, 2004; Hobday *et al.*, 2005).

Second, investment in product research and development (R&D) has not decreased and companies continue to spend significant financial resources on product innovations. Many of these innovations are upgrades to previous 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 maintain sales and reap profits from products, investment in product development is often necessary even for mature applications.

Therefore, many firms that move downstream by adding services continue to invest in product R&D and manufacturing. In this article we show that the difference between value creation and value capture may explain this. Technology changes may force or enable firms to change their business models (Chesbrough and Rosenbloom, 2002; Björkdahl, 2009; Baden-Fuller and Haefliger, 2013) by moving downstream because product innovations and services may be dynamically interdependent. A specific case of dynamic interdependence of products and services is when suppliers create value for customers by improving control over processes. A way to do this is by means of digitalization.[1] More precisely, advances in control technology can include integration of information and communication technologies (ICTs) into products which allow more dynamic control of production and operational processes for the customer.[2] Innovations in control technology by means of digitalization can create value for customers, but in general these innovations do not solve the appropriation problem faced by innovators, as there is a division of labor among firms where value created by one firm may diffuse to other firms or consumers (Levin *et al.*, 1987). This may force the supplier to change the way it tries to capture value, which may be achieved through changes to the business model through the provision of new services.

The article analyzes how firms profit from control innovations that reduce process uncertainty by studying two multinational corporations (MNCs). These companies renewed their offerings in sludge dewatering and compressed air businesses, respectively. The capabilities of suppliers in these fields traditionally are based on mechanical engineering skills. This article analyzes how firms integrate ICTs into their products, which gives rise to the provision of new services through augmented product offerings.[3] These types of control technologies are becoming increasingly pervasive across a range of applications and industries (Rosenberg, 1963; Nightingale *et al.*, 2003). In this article, ICT integration refers to when firms integrate ICT components or subsystems into products, which make the products more "intelligent." In the cases studied here, the ICTs can be classified as "hard" physical control technologies, a class of technologies that significantly improves the allocation of system traffic and reduces operation costs.

The article is organized as follows. Section 2 discusses the relation between increased control, and reduced uncertainty and "economies of throughput." It reviews the way that control is linked to new business opportunities and distinguishes between value creation and value capture. Section 3 outlines the case study approach, and Section 4 analyzes how two mechanical engineering MNCs reformulated their product offerings by providing integrated ICT. Section 5 discusses the findings and explains why some manufacturing firms may need to move downstream to capture the value from control innovations.

1 We can understand digitalization as the increased generation, analysis, and use of data to create value. Digitalization requires ICTs and the integration of such technologies into different parts of a firm's operations and its products.

2 The article shows that *dynamic* interdependencies among product innovations and services are reasons that are overlooked in explanations of firms move downstream by supplying complementary services. Dynamic interdependencies refer here to temporary mutual dependence of products and services for firms (Antonelli, 2001) to create and appropriate economic value. This notion stands in sharp contrast to bundling and integrated solutions, which refer to combined sales of products, and products and services, respectively, as single packages (Adams and Yellen, 1976; Davies, 2003, 2004). Dynamic interdependencies instead refer to the fact that appropriation of the returns from services may be temporarily dependent on the ability of the firm to deliver increasingly advanced products, and vice versa.

3 This should not be confused with "technology integration" (Iansiti, 1997), which refers to a particular mode of product development rather than to the nature of the product, which is the focus in this article.

2. Literature

Profit can be based on different ways of reducing uncertainty (Knight, 1921). Increased control is a powerful way to reduce uncertainty (Beniger, 1986; Chandler, 1992; Nightingale *et al.*, 2003). Control changes in firms or the economic system are related mainly to organization (e.g. routines), institutions (e.g. legislation), or technology (Beniger, 1986; Nelson, 1994; Nelson and Sampat, 2001). The literature on the economies of throughput has made important advances in terms of explaining how increased control allows the fixed costs of capital investments to be spread over larger amounts of output, across a specified period of time, resulting in lower unit costs and higher profits (Chandler, 1990, 1992; Nightingale *et al.*, 2003).

Chandler (1962, 1990) showed how improvements in throughput could improve capacity utilization, resulting in economies of scale and scope of production in which cost advantages are derived from high throughput. The higher the throughput, the greater the rate of return, meaning that up to some potential capacity the marginal cost fell with increased throughput, and increased if throughput decreased (Chandler, 1992). Chandler analyzed cases of manufacturers that cut their costs by achieving economies of scope and scale, resulting in higher profits when effective capacity utilization was assured and the market could absorb the products. The former allowed these firms to appropriate the returns on their investments, while the latter created economic value. "Chandlerian firms" were able to grow by matching product and service offerings to some characteristics (from the perspective of the products or services) of a large number of homogenous buyers or consumers.

The growth of the firm changed the nature of the managerial and technological problems (Penrose, 1959). Uncertainty and complexity grew beyond what individual managers could cope with and companies needed to adopt bureaucratic administrative processes to monitor current operations and the allocation of resources for future operations. Companies needed trained managers to monitor the flow of goods through the company, which, in turn, affected the organizational structure of these companies (Chandler, 1990, 1992). Techniques for monitoring and coordinating the processes within companies co-evolved with production technology and allowed throughput to increase and resources to be spread across product lines (Chandler, 1990; Davies, 1996). The ability for greater control generated economies of scale, scope, and speed[4] and made it possible for firms to continue to grow (Chandler, 1990).

However, if 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," which is directed and involves continual comparison between current states and future goals (Beniger, 1986: 6). Crisis of or lack of control comes from expansions in scale and scope which increase complexity. Therefore, lack of control can limit or destroy economies of scale, scope, and speed.[5] However, these obstacles to cost reductions create a locus for new *organizational* control systems and control innovations able to reimpose control (Hughes, 1983; Beniger, 1986). Beniger described successive advances in control as the control revolution.

The organizational focus has been complemented by work highlighting the role of control *technologies*. New control technologies used to control and coordinating subsystems can increase the performance of technical systems, 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 (Quinn, 1992; Nightingale and Poll, 2000).

Based on Davies (1996), Nightingale *et al.* (2003) analyze incorporations of software-intensive control technologies that significantly improve the allocation of systems traffic, thereby increasing throughput and performance. Nightingale *et al.* (2003) argue that innovations in control can increase the utilization of a fixed amount of installed capacity even when scale, scope, and speed are constant, without influencing the range of products. By optimizing

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

5 The first large technology system that required control to be re-established was 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 into railway networks, control problems produced diseconomies of scale in which operating costs increased with size (Beniger, 1986). This meant that companies could improve their scale and scope up to operational "dead ends" when control had to be re-established to shift scale and scope limits upward.

performance over interdependence of components, software-based control systems have the potential to increase accuracy, speed, scope, and reliability of control, and potentially to reduce costs (Nightingale *et al.*, 2003).[6]

An important implication from this article is that firms can identify and exploit the opportunities that reside in the economies of throughput logic discussed above. That is, the identification of new business opportunities based on increased control may imply a latent economic value that firms may create for customers. However, the means for appropriating this economic value often do not coincide with the means for creating the economic value.

For firms, the creation of value and the appropriation of economic value are crucial issues (Chesbrough and Rosenbloom, 2002; Björkdahl, 2009; Zott *et al.*, 2011). Creation of value and how firms appropriate it have been studied and highlighted in several bodies of literature (Lepak *et al.*, 2007). Some parts of the literature focus on value capture, while others focus on value creation. However, value creation is often confused with or confounded by value appropriation (Porter, 1985) where the sources or targets of value creation or capture may be any or all of business owners, stakeholders, or customers. Since the firm that creates value may not be able to appropriate this value, value creation and value appropriation should be viewed as distinct processes (Lepak *et al.*, 2007). This distinction is dealt with in the business model literature (Teece, 2010). In a similar vein, firm-level strategies require both the creation and appropriation of value, and it is this balance that is at the core of an effective firm strategy (Moran and Ghoshal, 1999).

Chandlerian firms were able to appropriate economic value because their physical and distributional assets, such as the size of their production plants, provided built in protection barriers. However, it is not generally true that the manufacturer or innovator receives a cost advantage from a product innovation and, thus, "automatically" appropriates the returns from the innovation. Indeed, often cost reductions benefit the buyer or operator of the physical goods regardless of whether the manufacturer of the physical goods cuts 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.

Leveraging a new technology requires that value is created in the first place and, if there is an economic value, this often needs to be distributed between manufacturer and user, a point that is largely neglected by the value chain literature. Hence, there is often a discrepancy between the appropriation of economic value by the firm that bore the uncertainty of innovation, compared to the creation of economic value that benefits the operator. To resolve this, the firm may need to reposition along the value chain and change its business model to appropriate economic value from the reduced costs for operators. The issue of appropriating economic value by increasing the throughput in customer processes based on new control technology systems is not addressed explicitly in the literature but would seem to have important implications for firm strategy.

3. Methodology

This article builds on two exploratory case studies (Eisenhardt, 1989; Dul and Hak, 2008) to explain why firms move downstream by adding services to profit from the value they create for customers through the provision of improved control. Both cases reflect the general phenomenon of huge investment in product innovation accompanied by a move into services to appropriate financial returns. The cases were selected because they are characterized by increased control that produces major economic benefits during operations.

The user applications in the case studies involve distinctive uncertainties due to the impossibility of a deliberately designed throughput for the operators of the machines in terms of inputs. This means also that, *unless* the operators can reduce this uncertainty during operation, the nature of the *outputs* is uncertain. This differentiates the applications described here from, for example, machine tools such as lathes and milling machines, which have well-defined inputs and where the nature of the outputs can more readily be controlled. We chose a case study rather than a variable-oriented approach, since our concern is not to test the theory but to formulate, elaborate, and refine concepts (Ragin, 1997).

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, 2003).

6 Control technologies are generally multitechnology. While we focus on hard control technologies, or more specifically control technologies based on ICT including software, other types of control technologies may be electronic, information, or physical-based (Nightingale *et al.*, 2003).

To some extent this limitation is reduced in that the cases are not focused on a specific sector or technology but are linked in the literature to the phenomena of control technology and integrated solutions in the established literature presented in *Industrial and Corporate Change;* on control technologies (Nightingale and Poll, 2000; Nightingale *et al.*, 2003) and integrated solutions (Davies, 2004).

Despite being based on different application areas, the two case studies are similar in terms of why centralized control systems were introduced (from the perspectives of both innovating firms and their customers) and the need to innovate business models to appropriate economic returns and the difficulties 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 the existing literature and theory, we adopted an iterative process between theory and evidence, starting from a loose set of ideas and frameworks from the existing theory. Because of the limited number of firms analyzed, this work should be seen as a continuation of Nightingale *et al.* (2003) on the under-researched role of control systems, and as a tentative first step toward understanding the large economic potential and business opportunities of control systems in customer applications by means of digitalization.

With the help of colleagues we followed the business development processes for 3 and 1.5 years, respectively, during May 2002 to June 2006. We followed the firms' business development processes before and/or after the launch of their various versions of control systems. This avoided 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. We conducted archival analysis of business plans, annual reports, and trade press. These data were complemented by 10 in-depth interviews with managers at a variety of hierarchical levels and in different functional positions, to obtain retrospective and prospective views on the new businesses, based on the introduction of new control systems. The interviews were conducted in Sweden, Denmark, and Belgium. Managers were asked to describe the reasons why the control systems were developed and the perceived business opportunities and challenges involved, from technical, strategic, commercial, and organizational perspectives. The semi-structured interviews lasted 1.5–3 h and were recorded and transcribed. To validate the data and results of the study, a draft of this article was circulated to the firms' managers who had been interviewed.

4. Case studies

4.1 Argon

The first case study analyzes how Argon, a Swedish MNC, increased throughput and control for customers running wastewater treatment plants, which reduced uncertainty and allowed customers to run more optimized processes for sludge dewatering (Björkdahl, 2007; Windahl, 2007; Björkdahl, 2009).[7]

Wastewater treatment plants treat effluent water and recycle clean (safe) water to watercourses (Qasim, 1999; Jördening and Winter, 2006). Argon manufactures decanter centrifuges designed to dewater sludge. The decanter centrifuges are used in the last step of the wastewater plant operations. Sludge dewatering is the most cost-intensive process in a wastewater plant, representing some 35% of total operating costs. A substantial part of the costs associated with sludge dewatering is for disposal of the sludge (Wang *et al.*, 2007). The dewatered sludge is normally transported to disposal sites by road or rail and a charge is made for disposal. The less water content in the dewatered sludge, the less costly it is to dispose of, as charges are based on the amount and weight of the sludge (Qasim, 1999; Dentel, 2001).

Sludge dewatering involves a high level of uncertainty because the quality and density of the feed are unpredictable. Thus the efficient operation of sludge dewatering requires high levels of attention. To decrease the amount of water in the sludge, it needs to be dosed with polymers before being fed to the decanter (Qasim, 1999). Without continuous attention, 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. If an experienced operator controls the dewatering process, the

7 The name of the corporation has been disguised for reasons of confidentiality.

decanter can run at around 70–80% 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 suboptimal process. The process reverts to low performance whenever an operator is not controlling it. To achieve the greatest efficiency requires three shifts of highly experienced operators working on the dewatering decanters. However, even experienced operators cannot achieve optimum performance from the decanter because of the complexity and uncertainty of the feed.

For decades, Argon has been the market leader in sludge treatment technology and has some 40% of the world market. During recent years, the product segment has been characterized by low profit margins because of the difficulty of differentiating increasingly commoditized products. The decanter technology was invented around 1950 and the main principle has not changed. Firms innovate incrementally, usually by making smaller, higher capacity decanters. Over the years, Argon has come up with new product generations that have provided the company with temporarily higher margins. However, competitors have caught up quickly lowering Argon's profit margins.

The complexity of the dewatering process means that the only improvement that can be made is to increase control over the process to ensure more efficient throughput. Beniger (1986) characterizes such processes as a two-way interaction between controller (here, the decanter) and controlled (here, the sludge) to communicate information through a feedback mechanism.

In the early 1990s, Argon's knowledge about customers' sludge separation processes was superior to that of their customers. However, this knowledge did not result in products superior to those of its competitors. To create value, the company sought to "productify" its new knowledge by adding ICT components and subsystems to its decanters. These changes to the technology were aimed at increasing control of the sludge dewatering process and reducing the uncertainty in its customers' operations. Argon recognized that the integration of ICT could enable substantial increase in the amount, speed, and quality of information exchanged between the controller and the controlled (e.g. in relation to the sludge going into the decanter and the output from the decanter), and could achieve a closer match between actual and intended output by measuring and modifying the input. This improved information would provide the operator with increased control over the amounts of polymers used. At the same time the new technology would increase accuracy allowing more precise control and decreasing the likelihood of catastrophic process failure. It would also increase the speed of control shifting it from the operator initiating action toward real-time control, which would improve the match between potential and actual performance. It would increase the scope of control, advancing it from local control of interdependent components to central control, which would allow for near optimal performance, and would increase reliability allowing the firm to move from reactive to proactive maintenance. Argon believed that its customers on their own would be unable to achieve these improvements to the application process because of their inferior knowledge about both the technology and the application process. Argon identified and acted upon the business opportunity represented by the need for greater control over the customers' process; it increased 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 first commercial sales. The idea to develop a control system that would improve output came from an Argon engineer who had started to develop a control system in 1991. The company had progressed substantially with development but encountered seemingly insurmountable problems related to continuous measurement of the characteristics in the sludge; it was unable to get a quality assured signal from the sludge. It was unable to continue development of the control system because the sensors available at the time were low quality. The project was shelved after a couple of years but restarted in 1999 when improved performance of sensors allowed more accurate measurement of the sludge. Hence, the initial opportunity and development of the control system were influenced by and were dependent on advances in ICTs.

In 2003 Argon launched, Octopus, a self-optimizing system for sludge dewatering. Octopus could monitor, analyze, and adjust the process parameters in the dewatering process (torque and differential from decanter, polymer dosing, concentration, and quality of sludge) in real time, and optimize the process for any process condition without the need for human supervision. The system could operate at near peak performance and optimize the dewatering process in terms of overall costs, solids recovery, and cake dryness, depending on the customer's priorities, and regardless of changes in feed conditions.

Octopus can be classed as a dewatering autopilot with optimization features, enabling much higher performance of the dewatering processes than could be achieved by an experienced operator.[8] Octopus reduced the operating costs of the dewatering process by up to 20%, corresponding to a saving of 7% 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 and polymer pumps, and the decanter. The sensors collected real-time data 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 company specific software, unique to the industry, that represented more than four decades of Argon's process knowledge and experience in decanter performance in dewatering applications, and determined the new control settings.

Argon saw Octopus as a real opportunity to reap some revenue from its knowledge, and as way for the company to differentiate itself from competitors that did not include control systems that could cut customers' costs. Although confident that the increased control would reduce uncertainty and represent economic value in the form of reduced costs for customers, Argon could not see how it could appropriate revenue from this without fundamental changes to its business model. That is, the company needed to find a way to capture returns from the economic value received by its customers.

Argon sold its products through capital sales and recognized the difficulties involved in getting payment for the increased customer value. The company's marketing unit which sold the decanters favored a package consisting of decanters equipped with the new control system (Octopus), marketed through capital sales in line with the traditional business model. Their choice was not solely based on tradition. Decanters are sold mostly through public tenders, seldom direct to end users, which reduces the forms of revenue models to capital sales. Public tenders impose certain specifications, and Argon knew that if customers did not understand the advantages to be gained from Octopus, it would not be successful. Selling Octopus with the decanter, through capital sales, would have resulted in the potential returns from increased customer value which the company could not appropriate.

The economic value to the customer in the form of annual cost savings based on increased control and reduced uncertainty was worth substantially more than the cost of a decanter during its life cycle.[9] Over 1 year, customers could make potential savings amounting to more than the cost of the equipment. These savings for the customer would continue but would have no economic value for Argon. To appropriate this value within the same business model would have meant a major price hike for the decanters. The management team judged that this was not feasible because the decanter market was price focused. It estimated that a new, higher priced product would have low market diffusion because it would represent a major investment for the customer, a perception reinforced by lost sales when customers applied a capital cost evaluation, although the company pointed out that a total life-cycle cost evaluation would give a different result.

In 2002, although it was a dramatic change in its business model, Argon decided to adopt an annual license fee model (service contract), based on the customers' cost savings, to capture value from Octopus. This change toward new services would reduce buyer resistance for three reasons: the service contract would be an operational rather than an investment cost for the customer, the license could be canceled if the customer was not satisfied, and the expenditure could be more easily related to savings. The license fee would qualify customers for free software updates, and since customers paid for uptime, 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 Argon if customers purchased Octopus without the services to handle break downs, etc. Because this way of doing business was entirely new for Argon, the management team decided to create a separate business unit to develop the new business services. These changes allowed Argon to offer an attractive value proposition and enabled it to appropriate a large portion of the customer savings.

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

9 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.

4.2 Krypton

The second case analyzes Krypton's introduction of a centralized control system for compressed air installations, which reduced customers' energy costs by improving utilization of installed capacity and providing increased reliability and productivity through process surveillance.[10] Compressed air is important in many industries, including manufacturing. A substantial part, around 30%,[11] of the energy consumed in industry comes from compressors (Source Newsletter, 2003). Compressed air is used as a source of power or as active air for industrial processes and, consequently, compressors are used in a wide range of applications. Increases in energy prices have made savings on electricity consumption increasingly important for many industries.

Compressors typically have local controls which ensure 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. The compressor unloads when the pressure reaches a predetermined level and loads when the pressure drops to a predetermined lower level. The range between these two pressure levels when the compressor loads and unloads is the compressor's set point. Local control works well where companies have a single compressor and steady demand, but most companies have a multiple compressor installation and add compressors as demand for compressed air increases. When the compressors are running in series, the load and unload pressures of the compressors need to be offset to prevent the compressors from starting up simultaneously. This way of connecting compressors is known as cascading and is traditionally used to handle increases in demand.[12] The combined minimum capacity of the compressors must be sufficient to meet the maximum air demand so that, to meet maximum air demand, a multiple compressor installation operating in a cascade needs to work at a higher pressure than a single standalone compressor. Since a company's demand for compressed air varies over time, it cannot be predicted, and since compressors do not operate at full-load all of the time, cascading becomes problematic because it limits the ability to closely match demand for air and creates a large pressure band. The result is a lot of wasted energy (Talbott, 1993, see especially Ch. 4). At the same time it creates unstable pressure, with shoots and undershoots of pressure that can affect customers' operations negatively.

Compressor technology has been a core business of Krypton for nearly a century, and since the 1930s, Krypton has been the world market leader both technologically and in terms of market share. Because of its long history the company had a large installed base of compressors, which it wanted to protect while at the same time increasing its revenues. In the 1980s and 1990s the mature compressor business was characterized by fierce competition and lower profit margins. Also, customers rarely replaced their compressors: with proper maintenance, compressors, in principle, can run indefinitely, although 10–15 years are considered the normal economic life span, usually because of the higher efficiency to be gained from a new compressor. Innovation in the compressed air industry has been based largely on advances in technology, with Krypton as the major actor. However, its product innovations did not work to increase Krypton's revenues substantially; they allowed the company only to stay in business.

For users of compressed air, energy costs are by the far largest expense over the compressor's life cycle (Office of Industrial Technologies, 1998). Energy consumption typically represents around 70% of the life-cycle costs of the overall compressed air system, while capital investment represents only some 20% and maintenance 10%.

In the 1990s, Krypton realized that if the company could lower energy costs, customers would save a tremendous amount of money over the compressor's life cycle. Compressed air installations always required a control system, but the need for more centralized control had increased over the years. Given that each compressor type had its own specific energy versus flow characteristics, and a widely varying optimum operating zone, efficient capacity utilization of multiple compressor installations was impossible without increased control. This development led to a "crisis of control" (Beniger, 1986): local control had become a highly inefficient way of running multiple compressor installations. Were control left to local compressor controllers in multiple compressor installations with no centralized real-time coordination, optimum utilization of the compressors was impossible to achieve. Central control systems were

10 The name of the corporation has been disguised for reasons of confidentiality.

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

12 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 four 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. 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.

needed to monitor, compare, and modify inputs and outputs to achieve a tight pressure band and match capacity to demand. This presented an opportunity for Krypton to reestablish and increase control in compressed air installations, and to turn centralized control and reduced uncertainty into cost reductions for customers.

In 1999, having identified a customer need to save energy and recognized an opportunity to generate more rents through a more integrated solution for compressed air installations, Krypton 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 reduction in the required working pressure through a signal, and increased control through control from one centralized control point instead of individual control of each compressor. Centralized control would take over from the local compressor controllers and work toward a common set point rather than one set point for every compressor. The control would allow real-time selection of the most energy efficient and optimal compressor mix and their operating points. The aim was to optimize compressor operation to allow users, as closely as possible, to match demand to compressor output. The control system had to be sufficiently "intelligent" to select which compressors needed to be run and to stabilize and lower the pressure to the lowest possible point.

Also, this would enable new types of services to be offered to customers. Central controllers for compressed air installations, allowing data from every compressor to be collected and processed, would facilitate remote monitoring of the compressed air processes. This would increase reliability and uptime resulting in fewer production interruptions, would increase efficiency resulting in reduced operational costs, and would facilitate access to valuable data on compressed air installations. This development was introduced in 1999 as an extension to the central controller development; the devices were connected between the central controller on one side, and an Internet connected machine on the other side, allowing both Krypton and the user to monitor all the machines and the compressed air process remotely. It allowed Krypton to collect and store data from users' compressed air installations, which was valuable information that could be used for other purposes. The monitoring and storage of data, and feedback from the process represented an externality on the basis of which Krypton could continue to build services. Krypton was able to start services on demand rather than having them based on timed intervals and tied compressor overview, data mining, etc., into service contracts.

Development of the advanced centralized controller was made possible by the integration of ICTs into the compressed air installation. The control system consists of hardware and software. The hardware comprises an industrial computer, a monitor, and a controller area network that links all local compressor controllers to a centralized controller unit, which is a computer and resembles a closed box. Similar to the case of the decanter control system, it is the software in the computer that is crucial 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 the compressors to keep the pressure within the user-defined pressure band, and to make decisions about which compressors need to be run. Interviewees claimed that these algorithms are based on Krypton's long experience and major manufacturing competencies and are highly company specific, and are the main reason why customers are unable to coordinate compressor installations on their own.

For Krypton, taking control over the customer's compressor installation was aimed at earning more money from the installed base. This was to be achieved by reducing the users' costs and uncertainty through increasing control over compressor installations, and by Krypton 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 that accrued to the customer from using the centralized control system, and Krypton failed to construct an architecture for obtaining revenue.

In 2002, when Krypton launched its centralized control system, it was no longer the only company 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, change 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 the day, and the day of the week. The sequences override the compressors' local controllers resulting in a tight pressure band. However, sequencers cannot coordinate the choice of compressors and can coordinate only a limited number and certain types of compressors. Control systems based on sequencing can control net pressure; thus, the resulting energy savings are not as great as those possible if the 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. Krypton was the only company able to offer such a system.

Krypton's control system enabled customer savings of about 10%. For customers, this economic value was more than the cost of the equipment over its projected life cycle (15 years). Because other companies were selling control systems through capital sales, Krypton thought it should do the same. It began to market its sophisticated control system at a very low price compared to the potential savings for customers. In 2003, Krypton had realized that this approach was not providing revenue for the company and introduced a license system (which included maintenance and upgrades) based on what customers would save, and which allowed the company to appropriate a larger part of the customer savings. However, few customers showed any interest because Krypton did not demonstrate how much money or energy could be saved. The customer wanted to see what it was paying for and found it difficult to believe that Krypton's system would be more energy saving than the controllers being offered by competitors; they told Krypton representatives that the financial viability of the new system needed to be demonstrated.

Within its then current business model, Krypton was not able to appropriate what it deemed to be a reasonable share of customer savings. Between 1999 and 2005, Krypton outlayed substantially more than the amount generated by sales of the control system. It tried to appropriate returns through a fixed or variable fee-based contract based on what customers would save, but because it was unable to convince customers about the potential savings in terms of money and energy, the contract offer was not successful. Krypton decided that to differentiate its offering it needed to develop the control further, and make the potential savings more tangible. This decision was based on the company's conviction that its solution was better than any being offered by competitors. Krypton believed that it could achieve repeat revenues by offering the control system as a service contract rather than a one-off sale, allowing it to appropriate a larger share of the customer saving while establishing a highly profitable business.

5. Discussion and conclusion

The starting point for this study was a simple empirical observation; if there are 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 several "obvious" reasons, including the fact that products and services may be complementary. However, in some instances, downstream moves of manufacturing firms can be explained by contrasting value creation and value capture in relation to increases in control and throughput by means of digitalization. In particular, in some cases there is more to the relationship between products and services than complementarity, a point that is not made explicitly in the literature dealing with moves along the value chain. This article analyzed the dynamic interdependence between product innovations and services in two cases. Indeed, the explanation is based on the difference between value creation and value capture (Teece, 1986) in that the creation of economic value for customers can emanate from improved control which leads to economies of throughput. However, it can be difficult for suppliers to capture the value from their investment, which may force them to innovate their business models through the inclusion of services. We discuss this in some detail below.

The cases of two multinational suppliers—in the sludge dewatering and compressed air businesses—that integrated ICT into their traditional product offerings showed that there may be dynamic interdependencies between products and services. In both cases, it is clear that the manufacturing companies made their investments to create economic value for customers through increased control over their operations, which led to value creation based on cost cutting during the operation. Thus, operators benefited throughout the entire product life cycle. For suppliers, however, appropriation of these cost savings was not directly related to the creation of economic value. This highlights that, often, there is a discrepancy between the creation of value for the customer and the appropriation of value by the supplier.

Sources of value creation for customers include the means to reduce uncertainty (Knight, 1921), and especially increased control. Section 4 showed that the firms' identification and exploitation of opportunities were based on increased control over customer processes. Hence, the identification and exploitation of opportunities were based on the perception and development of ways to create value for the customer. This is illustrated in (1) in Figure 1.

The two case studies showed how the companies identified and acted upon opportunities to reduce uncertainty in the operation of their products by integrating ICT into their offers. The inputs to the sludge dewatering and compressed air operations were uncertain for customers because they went beyond their knowledge and capabilities to control (or design) them. However, the ICT-based control systems greatly decreased the uncertainty of their operations by means of increased control. The new control systems were able to control the processes, with the use of less energy and resources and at lower cost. The increased control (and the decrease in uncertainty of operations)

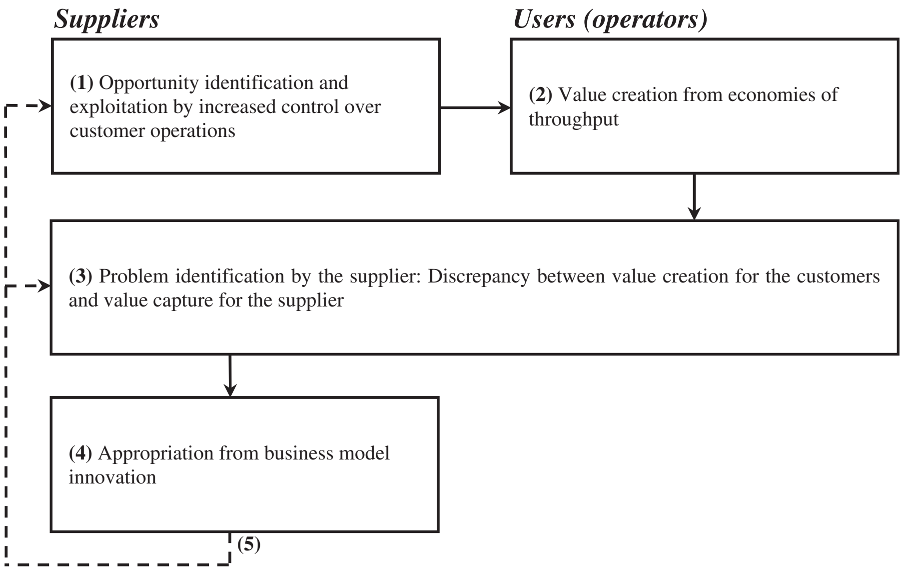

Figure 1. Uncertainty reduction, value creation, and appropriation in two case studies.

produced cost savings and quality improvements because the operator had greater control over operations (see (2) in Figure 1).[13]

The companies' innovative efforts and 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 enabled increased throughput. More precisely, data generation, analysis, and use by means of ICTs (digitalization) enabled increased control. This corroborates Beniger's (1986) argument that new control can shift the boundaries to bottlenecks in technical systems. Thus, we find that investments in product improvements are linked to value creation via reducing uncertainty by means of increased control, which, in turn, leads to cost reductions for the operator.

However, this does not automatically bring rewards for the supplier, because value creation is distinct from the appropriation of economic value (Moran and Ghoshal, 1999; Amit and Zott, 2001; Chesbrough and Rosenbloom, 2002; Jacobides *et al.*, 2006; Björkdahl, 2009); see (3) in Figure 1. This can be understood as a process of problem identification, which is determined by the difference between the existing situation and the desired situation, from the perspective of an individual actor (Pounds, 1969). The cases show that the firms identified problems in terms of appropriating value from the reduced costs for operators, within their current business models. That is, both firms realized that they could not reap any profit from the added customer value, using their existing business models. They could sell the product but could not achieve their objective of profiting from their investment in innovation. The firms identified a need to change their business models from selling the products to providing services under contract, to appropriate returns from the creation of economic value (see (4) in Figure 1). Such changes can lead to the repositioning of suppliers in the value chain, at least in the sense of undertaking new activities by creating them or taking on previous customer activities.

Although we do not discuss this explicitly in Section 4, there may be feedback loops (see (5) in Figure 1). We argue that these include (i) the identification of new business opportunities based on new means of uncertainty reduction, that is, new means–ends relations, including changes in control (McMullen *et al.*, 2007); (ii) internal learning based

13 The identification of the business opportunities for Argon and Krypton was connected directly to both the means of cutting customers' costs of operation and to appropriating a part of these cost savings to pay for the control systems. Argon achieved cost savings for customers by reducing the water content of the dewatered sludge, and reducing polymer consumption and human resources requirements; Krypton achieved these savings by reducing energy costs through coordinating the pressure of the compressors.

on customer behaviour and responses; and (iii) the actions of competitors that change the competitive landscape. However, as discussed in Section 4.2, Krypton changed its business model on the basis of feedback, by adding services to its product and, as a result of changes to the technology, is planning to shift to provision of services only.

From the perspectives of our proposed model and the two cases examined, products and services are dynamically interdependent; the creation of improved products is linked more to the creation of economic value, while the business model innovations related to services are linked to the 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, although it does apply in to the cases analyzed in this study. However, the sources of value creation and economic value appropriation vary, and we should not in the general case expect them to come together neatly.

An important issue is why the firms did not change their positions earlier; increased complexity and related problems of control are hardly a new phenomenon. It might suggest that increased control providing manufacturing firms with opportunities to add interdependent services to their products should have emerged much earlier. However, this would not have been possible, since the increased control achieved in both cases was based on ICT integration, which cut the costs of customers' operations. This technological advance was necessary and enabled the moves down the value chain. Our explanation therefore implies that many manufacturing firms will become service firms because of the opportunities enabled by digitalization.[14] However, this should not be seen as a technologically deterministic explanation: such changes do not just happen. As shown in our cases, it is necessary for managers to identify and act upon the opportunities. Thus, it was a combination of technological changes and a realization that the firms' business models needed to be changed to profit from the product innovation that explains the downward movement in both cases.

Two issues that emerge from this study warrant further research. One is the indication that there are temporary interdependences among the novelties of products and changes to firms' business models, leading to changes in the services provided by the firms. Little research has been done on how services relate to product innovations and throughput, including investigation of the sustainability of the competitive advantage. The second is that there are limits to what we can say about the relation between value creation, appropriation, and products and services, based on our case studies. However, we would suggest that the explanation proposed in this article may be more generally applicable. We would suggest that the core notions explaining the dynamic interdependence between services and product innovations include (i) increased control, (ii) throughput, (iii) value creation, and (iv) value capture. The theoretical foundations of this explanation include the throughput literature, which discusses why and how companies become dominant by appropriating returns achieved from increased control, to reap the economies of scale and scope (Clark, 1923; Chandler, 1962, 1990; Nightingale *et al.*, 2003), and the value creation and value capture literature, which investigates changes in specialization and the role of appropriation (Teece, 1986; Chesbrough and Rosenbloom, 2002; Davies, 2004).

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14 This prediction is in line with the literature on servitization and product–service systems (Neely, 2008; Baines *et al.*, 2009; Visnjic Kastalli *et al.*, 2013; Visnjic Kastalli and Van Looy, 2013). However, they lack a theoretical explanation and a mechanism for why manufacturing firms will become service firms by means of digitalization.

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