An Analysis of Usage-Based Pricing Policies for Smart Products

FRÉDÉRIC THIESSE AND MORITZ KÖHLER

A b s t r a c t

This contribution concerns itself with the potential of Usage-Based Pricing policies for smart products. We develop an analytical model of a supplier of machines and a customer that allows us to compare Usage-Based Pricing to a traditional scheme with fixed prices, and to determine optimal solutions for both parties. Based on these findings, we discuss the value of Usage-Based Pricing on an operational as well as on a strategic level. The main conclusion that can be drawn from our research is that Usage-Based Pricing does not provide any additional value that could not also be achieved by information sharing and joint price optimization. From a more strategic perspective, however, we find that the transfer of demand risk from the customer to the supplier implied by Usage-Based Pricing might be used as a strategic tool to attract new prospects and to enter new markets, but only to a lesser extent as a means to keep existing customers.

Keywords: pricing, sensor technology, ubiquitous computing, smart products, revenue management, yield management

INTRODUCTION

Practical relevance

In recent years, strategies and procedures for the optimal pricing of goods and services have received wide attention in both theory and practice. Among the newly emerging concepts, for example, is so-called 'scientific pricing' (Phillips 2005), a term that is often used synonymously with 'revenue management' and 'yield management' (Boyd 2007: 8, Kuyumcu 2007). Scientific pricing denotes a systematic approach to the question of what to sell to whom at what price; its goal is to increase revenues for the seller of a good or service. Practical application cases can be found, for instance, in the airline industry, hotels, or car rental businesses. Due to the rapid developments in enterprise information systems and a new quality of available data, pricing becomes a streamlined software-driven business process (Valkov 2005), which involves the most profit-sensitive decisions as it directly influences sale-purchase transactions. As Kuyumcu (2007) notes, companies can no longer afford to fail in their pricing decisions; all products and services must be priced right, at all times. To make this process more challenging, the right price today may not be the right price tomorrow, as business conditions continuously change.

One of the novel pricing models that are currently discussed in both practice and academia is the concept of so-called 'Usage-Based Pricing'. The key idea has been known for quite some time from the pricing of services in the virtual world of the Internet, where customers are charged for the time they make use of a service (Kim 2005), e.g. broadband Internet access, access to multimedia content, business software applications and grid computing. Similar payment models are also well-known from video-on-demand services ('pay-per-view'), cellular phones ('pay-as-you-go'), and online advertising ('pay-per-click'), among others.

With the advent of RFID, location systems, wireless sensors, and other Ubiquitous Computing technologies, the concepts of Usage-Based Pricing are increasingly finding their way into the world of physical products as well (Allmendinger and Lombreglia 2005). One of the first examples has been Accenture's prototype implementation of a 'pay-per-use chair', which contains a microscopic sensor in the base that reacts to weight and temperature, while measuring usage time with an embedded clock (Accenture 2007). With the help of the collected data,

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the owner of the chair could charge his customer only for the time the object was used, e.g. in the case of renting furniture for one-of occasions such as weddings or conferences. A real-world example that was not only made for demonstration purposes is CONTURA G2, an industrial measuring device made by Germany-based Carl Zeiss AG. The product is both available at a fixed price for purchase as well as on a pay-per-use basis, in which customers receive a CONTURA G2 system for 12 months and must only pay actual usage fee (Zeiss 2006).

Research question and structure

Against this background, this contribution concerns itself with the potential of Usage-Based Pricing policies for smart products, which are enabled by automatically collected sensor data on product usage. Our research is motivated by the question, to what extent suppliers and users of smart products can draw quantifiable benefits from Usage-Based Pricing. For this purpose, we develop an analytical supply chain model of a supplier of machines and a customer, which allows us to compare Usage-Based Pricing to a traditional scheme with fixed prices, and to determine optimal solutions for both parties. Based on these results, we aim to discuss the value of Usage-Based Pricing on an operational as well as on a strategic level.

The remainder of the paper is organized as follows. In the next section, we provide an overview of the technological background of our research. The following section comprises a review of the existing body of related literature on pricing models with a specific focus on Usage-Based Pricing. Then, we present an analysis of the traditional and the usage-based policy using a formal model of a simple supply chain involving two partners that have to agree on a pricing policy. We illustrate the potential benefits of shifting to Usage-Based Pricing on a numerical example and discuss the resulting managerial implications. The paper closes with a summary and an outlook on further research.

TECHNOLOGICAL BACKGROUND

The basic concepts of so-called 'Ubiquitous Computing' were developed more than 15 years ago by Mark Weiser, a chief research scientist at the Xerox PARC, in his article *The Computer for the 21st Century* (Weiser 1991). The term denotes the vision of a future world of 'smart objects', i.e. physical items whose physical shape and function are being extended by digital capabilities in order to support their users, invisibly and unobtrusively, in their tasks and activities (Bohn *et al.* 2003, Maass and Filler 2006). Whereas Weiser's ideas seemed rather utopian at the time, the widespread use of Ubiquitous Computing technologies is nowadays becoming reality. Miniaturization and price decline of information and communication technology increasingly result in processors and sensors being integrated into everyday objects, which serve as the technological foundation for a variety of applications in the context of business processes within the firm as well as in the private domain of consumers (Ferguson 2002). The ability of an object to store a unique identification code and report it to its environment constitutes the first step toward the integration of objects and information, and provides the basis on which farther-reaching functionality can be built (Want 2004).

From a management perspective, Ubiquitous Computing technologies have the potential to eliminate the media break between physical processes and the associated information processing (Fleisch and Thiesse 2007, Jonsson *et al.* 2008). They enable a fully automatable machine-to-machine relationship between tangible items and information systems by equipping the former with microelectronic components. They help to reduce the costs of depicting physical resources and operations in information systems by assuming the role of mediator between the real and the virtual world. A descriptive example is an industrial container that knows its position, contents, and temperature and transmits this information automatically to the inventory management system of a distribution centre on arrival at the docking door.

These applications are made possible by the widespread deployment of sensor technology, which enables systems to sense changes in state in the real world automatically (Abowd *et al.* 2002). Sensors have been applied in industries such as manufacturing or chemical processing for several decades. In these settings, sensors were part of repetitive closed loop control processes and were usually connected to machines or process control systems through proprietary protocols. Only through the emergence of packet-based network technologies in both fixed line and wireless networks, could sensing be lifted to the next level in the form of sensor networks. Through research efforts which started in the mid 1990s, application developers are now at a point where they can use sensors as a commodity building block of their applications making it easy and cost effective to integrate them on a large scale. Latest efforts in sensor network research focus on the development and deployment of high level protocols such as Web Services and large scale integration architectures (Moreira *et al.* 2008). These developments provide hope for even easier integration of sensor networks in enterprise software systems and are a next step towards a real time enterprise. For a more detailed technical discussion of sensor networks, the interested reader is referred to Akyildiz *et al.* (2002) as well as Karl and Willig (2005).

On the one hand, it is evident that these technologies allow for various kinds of process improvements, e.g. in retail logistics or manufacturing. On the other hand, ubiquitous computing also enables smart products and associated services (Allmendinger and Lombreglia 2005, Fano and Gershman 2002, Roberti 2006), i.e. human beings relinquish a part of their control tasks which up to now they have performed themselves due to their capability to generate high-quality depictions to things and services. Smart products are in this sense products which achieve additional functions as a result of the new higher depiction quality through ubiquitous computing technology. They make their functions dependent on their immediate surroundings, on the proximity, relationship, familiarity and history of the components, the means of production, the wear parts, the spare parts and the tools with which they interact. Products thus become a process interface and a new source of information for the manufacturer and users.

RELATED WORK

Ubiquitous computing technology offers possibilities not only for enhancing physical products but also for linking these with information and services on the Internet. Examples of services of this kind are pay-per-use pricing models that we now consider in more depth. Due to the novelty of the concept in the context of smart products, the number of related academic contributions is very small. The underlying idea of charging a customer for the time that he makes use of a service, however, has been discussed extensively in scholarly contributions on Internet services. This section therefore reviews the literature from this domain as far as it is relevant to the research presented in this paper.

In recent years, major research efforts have been made on pricing concepts for package-based communication networks, due to the fact that sophisticated pricing of data transmission services may support congestion control and improved overall network usage. As DaSilva (2000) states in his survey of research works, '[quality of] service differentiation in communication networks brings about a clear need for incentives to be offered to users to encourage them to choose the service that is most appropriate for their needs, thereby discouraging over-allocation of resources, which in commercial networks can be most effectively achieved through pricing'. Another overview of pricing concepts for broadband IP networks was, for example, given by Falkner *et al.* (2000).

Courcoubetis *et al.* (2000) conducted a study of usage-based charging schemes for broadband networks. They showed the compatibility of incentives for Usage-Based Pricing in regards to the relative amount of resources used by connections. Odlyzko (2001) argues that sophisticated pricing schemes in communication networks like price differentiation based on 'Quality of Service (QoS)' are likely to be substituted by simpler schemes due to the fact that the quality of services constantly increases whereas costs of the same decrease. Bichler *et al.* (2002) provide a review of research on flexible pricing, including both differential-pricing and dynamic-pricing mechanisms, such as auctions. In their work they conclude that successful utilization of flexible pricing in contrast to fixed pricing can significantly enhance a company's competitive advantage and help manage changing market demands, if it is integrated with real-time end-to-end supply chain management.

Altmann and Chu (2001) propose a combined pricing scheme for network services, offering the consumer a flat-rate with relatively low QoS combined with a usage-based tariff for services with higher QoS. The authors argue that such a pricing scheme is attractive to users and allows providers to build a sustainable business. An approach called 'Paris Metro Pricing (PMP)', which is not based on QoS but on partitioning of the network into logical channels, was proposed by Odlyzko (1999). Ros and Tuffin (2003) present a mathematical model for PMP. Blefari-Melazzi *et al.* (2002) present an approach to measure network service quality as a function of the performance guarantees of the transfer service. The authors propose a pricing law to charge improved IP services depending on the duration of the connection and on the traffic volume exchanged during the communication. In their model, the tariff is a function of the actually used and/or reserved network resources, so as to satisfy the requirements of users and network management, respectively.

Close to the pricing problem for services delivered by networks such as pure data transportation, is the problem of pricing services delivered through networks like CPU time or storage. Paleologo (2004) presents a Price-at-Risk methodology towards pricing of utility computing services. Buyya *et al.* (2001) present an economical framework for computational grids that are executing large-scale resource-intensive applications. The authors discuss different pricing policies based on usage time, QoS, auctions, etc. Through modelling factors such as uncertain rate of adoption this methodology can account for risk before the pricing decision is made. Kenyon (2005) proposes a solution to the problem of designing a pricing scheme for outsourced IT infrastructure and business processes. Through decomposition of the event space – where events are, for example, client requirement histories – a solution can be found yielding Pareto-efficient outcomes with respect to the Provider and the Client, which then can be used as a basis for contract negotiations. Oh (2007) shows that Usage-Based Pricing is in fact superior to fixed pricing for network access and media content in regards to social welfare maximization and the purpose of consumers' welfare maximization.

A new problem of pricing software arouse when networks became powerful enough to allow service-based software application delivery (i.e. Application Service Providing, Software as a Service). Gurnani and

Karlapalem (2001) investigate the advantages of disseminating software on the Internet on a pay-per-use basis in comparison to conventional selling. The authors examine the benefits for the software vendor as well as the impact on the software market size. Cheng and Koehler (2003) model the economics of the provider of a software application service and its potential customers, which allows for deriving an optimal pricing policy for the service provider. Their studies suggest the existence of an optimal server capacity where profits start to decline as the increased revenues fail to cover increased server costs. Liu *et al.* (2003) present a general model that allows for analyzing optimal price structures in e-commerce markets, both flat and usage-based. The authors explicitly model the spread of price-QoS trade-offs across the end-user population.

In contrast to these prior works, our research has its focus on the transfer of the principles of Usage-Based Pricing from network-based services to the use of sensor-equipped physical products such as industrial equipment. Our contribution to the literature comprises an investigation of the new pricing scheme in the context of a supply chain consisting of one supplier and his customer. This setting allows us to derive optimal solutions for both parties and to compare these to a policy with fixed prices.

MODEL DEFINITION

Conceptual approach

In this section, we develop an analytical model for comparing Usage-Based Pricing (UBP) of physical products to a traditional Fixed Price (FP) policy. We consider the example of the manufacturer of machines and a customer, who uses this machine type to fulfil some kind of demand in the market. Under the FP policy, the customer has to make an initial decision on the machine capacity that he is willing to invest in, such that he yields an optimum between machine purchase costs on the one hand and sales revenues on the other hand. However, no matter what decision he makes, he inevitably suffers from unused machine capacity if demand is low or from lost sales if demand is high, respectively (cf. Figure 1). These inefficiencies pose the potential for improvement through the implementation of new pricing models.

The promise of UBP is to solve this dilemma and to create a win-win situation advantageous to both the manufacturer and the customer. The underlying idea is to integrate sensors in the machine that measure actual usage, e.g. in terms of the number of processed items, uptime, machine performance, power consumption, and so on. Depending on the parameters that are used as a foundation for the UBP model, payments for machine capacity can be adapted more flexibly to the customer's needs. As a consequence, the customer's payments converge toward the demand he is facing and the prior mentioned inefficiencies drop to a minimum. Of course, it should be noted that setup times and other characteristics of the machine usage process will prevent the reduction of inefficiencies to zero in most real-world situations. However, it seems evident that the customer benefits from decreasing overcapacity cost while revenues increase due to the reduction of lost sales. To motivate the manufacturer to agree to UBP, the two parties may negotiate a pricing model that leads to higher revenues for both sides.

In order to investigate these concepts in more detail, we model a simple supply chain as depicted in Figure 2, which comprises a supplier S and a customer C. C serves

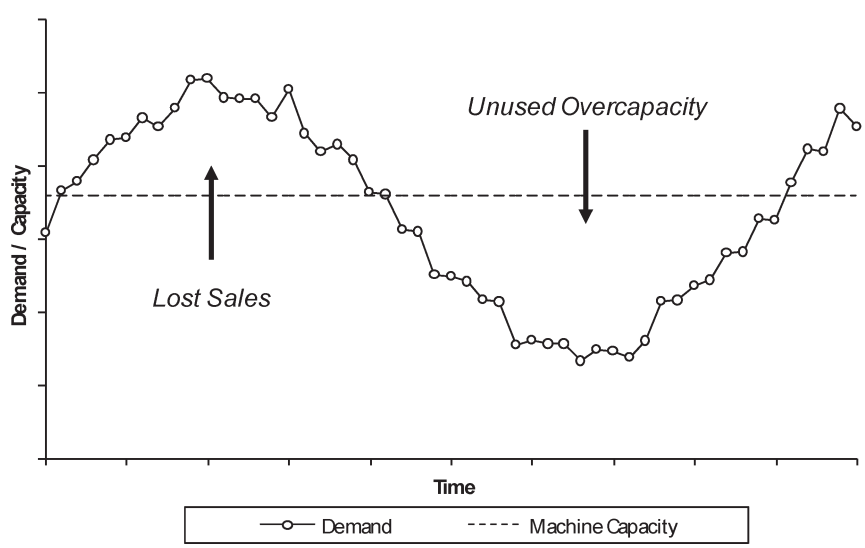

Figure 1. Issues with predetermined machine capacity and stochastic demand

Figure 2. Overview of model structure

a market that is characterized by a cumulative demand distribution function Φ. C's products generate revenues $r > 0$ per sold unit. The manufacturing of these products requires a specific type of machine with a fixed production capacity of m units per time period: $m \in \mathrm{N}$. We assume a purchase price $p > 0$ per machine, which is given by the market and exogenous to our model. C's decision problem is to determine an optimal number n of machines that leads to maximal profits; $n \in \mathrm{N}$.

On the part of S, the manufacturing of a machine of this type generates manufacturing costs c with $p \geqslant c > 0$, i.e. S's margin equals $p - c$. Note that m, p, and c do not refer to the machine's total lifecycle but rather to a fixed planning period T to make revenues and costs comparable. In the following sections, we first model the described FP policy and then contrast this with a UBP policy, which splits the price per machine into a fixed fee f with $p \geqslant f \geqslant 0$ and a usage-dependent variable fee $v \geqslant 0$. In order to make statements on the corresponding potential for improvement, we determine upper bounds for the additional profit for C and S, respectively. For the sake of simplicity, we knowingly exclude some aspects from our model, which would have to be taken into account under real-world conditions, such as the influence of competition and the time value of money (i.e. discounting). A reference list of the model parameters is given in Table 1.

Table 1. Reference list of model parameters

Parameter	*Explanation*
c	Manufacturing cost per machine
f	Fixed usage fee per machine
FC(n)	Customer's objective function (i.e. profit from product sales)
FS(n)	Supplier's objective function (i.e. profit from machine sales)
m	Production capacity (i.e. units) per machine
n	Number of machines at customer's site
p	Fixed purchase price per machine
r	Customer's revenue per sold product unit
v	Variable fee per produced unit
Φ	Cumulative distribution function of demand for customer's products

MODEL UNDER THE FIXED PRICE POLICY

Customer perspective

In this section, we develop C's profit function, which depends on the number of available machines n. $n \cdot m$ denotes the maximum number of units that can be produced per period. Under the assumption that $i-1$ units were produced, the marginal revenue from selling one more unit is given by $r(1-\Phi(i))$. Accordingly, the expected total revenue per period is given by the following term:

$$\sum_{i=1}^{n\,m} r(1-\Phi(i)) \tag{1}$$

On the other hand, C has to acquire machines at a total purchase price $n \cdot p$. In order to determine the optimal n, we relax the decision problem by treating n as a real number and Φ as a continuous distribution function. C's objective function $F_{FP}^{C}(n)$ can accordingly be formulated as:

$$F_{FP}^{C}(n) = r \int_{0}^{n\,m} (1-\Phi(x))\mathrm{d}x - n\,p \tag{2}$$

If n is chosen too small, C might suffer from high lost sales; if n is too large, C spends money on machines whose utilization level is too small to justify the purchase price. We find the optimal number of machines n_{FP}^{*} by equating the derivative of $F_{FP}^{C}(n)$ to zero:

$$\begin{aligned} & r\,m(1-\Phi(n\,m)) - p = 0 \\ & \Leftrightarrow n_{FP}^{*} = \frac{\Phi^{-1}\left(-\frac{p}{r\,m}+1\right)}{m} \end{aligned} \tag{3}$$

Supplier Perspective

S's profit per machine is given by $p - c$, i.e. profits increase linearly with n. The corresponding objective function $F_{FP}^{S}(n)$ can accordingly be formulated as:

$$F^S_{FP}(n) = n(p-c) \tag{4}$$

MODEL UNDER THE USAGE-BASED PRICING POLICY

Customer perspective

Under a UBP policy, C has to pay a variable fee v, which decreases his revenue per sold unit. On the other hand, he pays fixed fees f per machine, which are usually lower than the traditional market price p. Note that $v>0$ and $f=0$ denote a policy with maximum flexibility for C. In most cases, however, S will charge at least a small base fee to keep C from ordering excessively large amounts of machinery. In turn, $v=0$ and $f=m$ equal the previously described case of fixed prices. C's objective function under Usage-Based Pricing is given by:

$$F^C_{UBP}(n) = (r-v)\int_0^{n\,m}(1-\Phi(x))\mathrm{d}x - n\,f \tag{5}$$

In order to calculate the maximum benefit for S under UBP, we need to determine a combination of v and f, which leads to the same profit for C as under the FP policy. For this purpose, we equate C's objective function to the optimal result in the traditional scenario $F^C_{FP}\left(n^*_{FP}\right)$ and solve the equation for v:

$$\begin{aligned}
&F^C_{UBP}(n) = F^C_{FP}\left(n^*_{FP}\right)\\
&\Leftrightarrow (r-v)\int_0^{n\,m}(1-\Phi(x))\mathrm{d}x - n\,f\\
&= r\int_0^{n^*_{FP}\,m}(1-\Phi(x))\mathrm{d}x - n^*_{FP}\,p\\
&\Leftrightarrow v^{C,min} =\\
&-\frac{-r\int_0^{n\,m}(1-\Phi(x))\mathrm{d}x + n\,f^{C,min} + r\int_0^{n^*_{FP}\,m}(1-\Phi(x))\mathrm{d}x - n^*_{FP}\,p}{\int_0^{n\,m}(1-\Phi(x))\mathrm{d}x}
\end{aligned} \tag{6}$$

$v^{C,min}$ and $f^{C,min}$ denote a combination of fees that leads to no additional profits for C at all, i.e. under this scheme, S would keep all the benefits for himself.

Supplier perspective

The shift from FP to UBP is associated with a fundamental change in business practices for S since his revenues now partially depend on C's sales. S's objective function is given by:

$$F^S_{UBP}(n) = v\int_0^{n\,m}(1-\Phi(x))\mathrm{d}x + n(f-c) \tag{7}$$

In order to calculate the maximum benefit for C under UBP, we equate S's objective function to the optimal result in the traditional scenario $F^S_{FP}\left(n^*_{FP}\right)$ and solve the equation for v:

$$\begin{aligned}
&F^S_{UBP}(n) = F^S_{FP}\left(n^*_{FP}\right)\\
&\Leftrightarrow v\int_0^{n\,m}(1-\Phi(x))\mathrm{d}x + n(f-c) = n^*_{FP}(p-c)\\
&\Leftrightarrow v^{S,min} = -\frac{n\,f^{S,min} - n\,c - n^*_{FP}\,p + n^*_{FP}\,c}{\int_0^{n\,m}(1-\Phi(x))\mathrm{d}x}
\end{aligned} \tag{8}$$

$v^{S,min}$ and $f^{S,min}$ denote a combination of fees that leads to no additional profits for S at all, i.e. under this scheme, C would keep all the benefits for himself.

ENHANCEMENT POTENTIAL OF USAGE-BASED PRICING

Now that we have determined fees that lead to profits for only one of the two parties, we can calculate upper bounds for the additional profit that could be yielded by implementing UBP from the perspectives of both sides. With regard to C, we consider the definition of $F^C_{UBP}(n)$ and substitute parameter v by $v^{S,min}$:

$$\begin{aligned}
F^{C,max}_{UBP}(n) &= \left(r + \frac{n\,f^{S,min} - n\,c - n^*_{FP}\,p + n^*_{FP}\,c}{\int_0^{n\,m}(1-\Phi(x))\mathrm{d}x}\right)\\
&\int_0^{n\,m}(1-\Phi(x))\mathrm{d}x - n\,f^{S,min}\\
&= r\int_0^{n\,m}(1-\Phi(x))\mathrm{d}x - n\,c - n^*_{FP}\,p + n^*_{FP}\,c
\end{aligned} \tag{9}$$

$F^{C,max}_{UBP}(n)$ denotes C's objective function under the assumption that S's profits do not change under UBP. We find the optimal number of machines for this case by equating the derivative of $F^{C,max}_{FP}(n)$ to zero:

$$\begin{aligned}
&r\,m(1-\Phi(n\,m)) - c = 0\\
&\Leftrightarrow n^*_{UBP} = \frac{\Phi^{-1}\left(-\frac{c}{r\,m}+1\right)}{m}
\end{aligned} \tag{10}$$

Equation (10) can be interpreted such that an optimum exists if the expected revenues from selling the first m products are greater than the manufacturing cost of a machine, i.e. $m(1-\Phi(m))r > c$. Otherwise, an economically viable solution cannot be found.

With regard to S, we consider the definition of $F^S_{UBP}(n)$ and substitute parameter v by $v^{C,min}$:

$$\begin{aligned}
F^{S,max}_{UBP}(n) &= r\int_0^{n\,m}(1-\Phi(x))\mathrm{d}x - n\,f^{C,min}\\
&-r\int_0^{n^*_{FP}\,m}(1-\Phi(x))\mathrm{d}x + n^*_{FP}\,p + n\left(f^{C,min} - c\right)\\
&= r\int_0^{n\,m}(1-\Phi(x))\mathrm{d}x - r\int_0^{n^*_{FP}\,m}(1-\Phi(x))\mathrm{d}x\\
&+ n^*_{FP}\,p + n\,c
\end{aligned} \tag{11}$$

$F_{UBP}^{S,max}(n)$ denotes S's objective function under the assumption that C's profits do not change under UBP. We find the optimal number of machines n_{UBP}^{*} for this case by equating the derivative of $F_{FP}^{S,max}(n)$ to zero:

$$\begin{aligned} & r\,m(1-\Phi(n\,m))-c=0 \\ & \Leftrightarrow n_{UBP}^{*}=\frac{\Phi^{-1}\left(-\frac{c}{r\,m}+1\right)}{m} \end{aligned} \tag{12}$$

Note that equations (10) and (12) are the same, which indicates that n_{UBP}^{*} is independent from the decision on who eventually benefits from UBP. Strictly speaking, n_{UBP}^{*} does neither depend on v nor on f at all, and the optimum can be derived from the manufacturing cost of a machine and the market price of C's products only. Note also the similarity to expression (3), which indicates that $n_{UBP}^{*}=n_{FP}^{*}$ if C is able to purchase machines at a price that equals their manufacturing cost (i.e. $p=c$). An important conclusion that can be drawn from this is that the optimal n_{UBP}^{*} is the same as the optimal number of machines in an integrated company, which is both manufacturer of machines and products.

NUMERICAL EXAMPLE

Results under the fixed price policy

In this section, we illustrate the consequences of shifting from a FP policy to UBP with the help of a numerical example and discuss the main conclusions that can be drawn from it. We assume normal distributed demand for C's products with $\mu=1000$ and $\sigma=300$. C's Revenues per sold unit are $p=1$. S's machines are characterized by $m=100$, $p=70$, and $c=50$. The resulting values of the objective functions for both parties under the FP policy are depicted in Figure 3.

In the case of the normal distribution, Φ^{-1} cannot be expressed in closed form. We therefore calculate the optimal number of machines that C will invest in numerically from expression (3):

$$n_{FP}^{*}=8.42679 \tag{13}$$

From expressions (2) and (4), we can then calculate the optimal profits for both parties from C's perspective:

$$F_{FP}^{C}\left(n_{FP}^{*}\right)=195.72583, F_{FP}^{S}\left(n_{FP}^{*}\right)=168.53596 \tag{14}$$

These values, however, do not represent valid results under the condition that n has to be an integer value. It is therefore necessary to round up and down, and to compare the resulting profits to come to an optimal solution for the original model before relaxation:

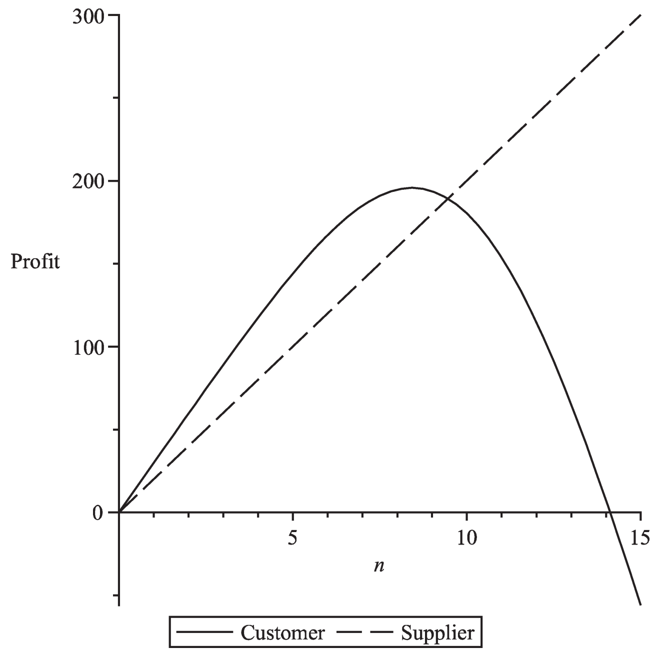

Figure 3. Profits for S and C under the fixed price policy

$$F_{FP}^{C}\left(\lfloor n_{FP}^{*}\rfloor\right)=194.69772, F_{FP}^{S}\left(\lfloor n_{FP}^{*}\rfloor\right)=160.00000 \tag{15}$$

$$F_{FP}^{C}\left(\lfloor n_{FP}^{*}\rfloor\right)=193.76278, F_{FP}^{S}\left(\lfloor n_{FP}^{*}\rfloor\right)=180.00000 \tag{16}$$

We see that C could generate slightly higher profits from only eight machines than from nine.

RESULTS UNDER THE USAGE-BASED PRICING POLICY

From expressions (10) and (12), respectively, we can numerically calculate the optimal number of machines under the UBP policy:

$$n_{UBP}^{*}=10.00000 \tag{17}$$

In order to investigate the advantages of the new pricing model, we first consider the maximum benefits for C. For this purpose, we insert n_{UBP}^{*} into equation (8):

$$\begin{aligned} & v^{S,min}=-0.01135\cdot f^{S,min}+0.75939 \\ & \Leftrightarrow f^{S,min}=-88.03509\cdot v^{S,min}+66.85359 \end{aligned} \tag{18}$$

We conclude from these two terms that $v^{S,min}\in[0,0.75939]$ and $f^{S,min}\in[0,66.85359]$. From equation (18), we can now calculate a valid combination of f and v, and insert them into equation (9), which leads us to C's maximum profit under UBP:

$$F_{UBP}^{C,max}\left(n_{UBP}^{*}\right)=211.81497 \tag{19}$$

In comparison to the FP policy, C could increase his profits by 8.79%. It is important to note that in our specific numerical example, n^*_{UBP} is already an integer value. In most other cases, however, we would have to round up and down as previously under the FP policy in order to calculate valid results for F^C_{UBP}.

In a second step, we consider the maximum benefits for S. For this purpose, we insert n^*_{UBP} into equation (6):

$$v^{C,min} = -0.01135 \cdot f^{C,min} + 0.77767$$
$$\Leftrightarrow f^{C,min} = -88.03509 \cdot v^{C,min} + 68.46251 \quad (20)$$

We derive from these two terms that $v^{C,min} \in [0,0.77767]$ and $f^{C,min} \in [0,68.46251]$. From equation (20), we can now calculate a valid combination of f and v, and insert them into equation (11), which leads us to S's maximum profit under UBP:

$$F^{S,max}_{UBP}\left(n^*_{UBP}\right) = 184.62509 \quad (21)$$

In comparison to the FP policy, S could increase his profits by 15.39 %.

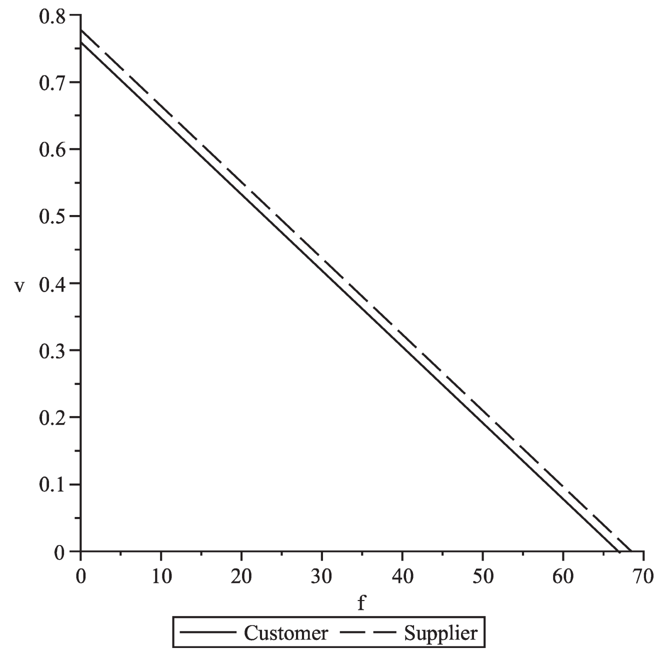

Figure 4. Decision space under the usage-based pricing policy

CONCLUSIONS

In the previous subsection, we have found combinations of v and f that lead to optimal profits under UBP for S and C, respectively. Nevertheless, there still remains the tricky question how to agree on a compromise between these two extremes that results in shared benefits. In our numerical example, the companies' decision space is delimited by equations (18) and (20) as well as $v \geqslant 0$ and $f \geqslant 0$, which corresponds to the area between the two lines and the two axes as depicted in Figure 4. The answer to this question can obviously not be given from within our model but is rather the result of negotiations between the two parties, which are influenced by a plethora of internal and external factors.

Our decision problem can be further divided into two separate aspects that we discuss in the following. On the one hand, the two supply chain partners have to agree on the extent of benefit sharing, i.e. on the question whether one party can afford to keep most of the benefits for itself or not. In the context of Figure 4, this corresponds to the distance between a valid solution and the two lines. The decision to be made depends on the kind of partnership between C and S, the overall distribution of power in an industry, the level of trust and cooperativeness between supply chain partners, etc. In the automotive industry, for example, OEMs are usually in the convenient position to be able to issue technology mandates on their suppliers; similar structures can be found in retail and aerospace. In other industries, however, it might be the supplier who benefits most from UBP while his customer is fobbed off with the vague promise of increased flexibility.

On the other hand, C also has to make a fundamental decision on to what extent he is willing to shift from FP to UBP by generating revenues more from variable fees per produced unit than from fixed fees per machine. In the context of Figure 4, this corresponds to the position of a valid solution on the horizontal axis. An important conclusion that we can draw from equations (10) and (12), however, is that UBP is not per se advantageous over FP. As we can see from equations (18) and (20) in our example, a valid optimum can always be found for $v=0$, i.e. the apparent benefits of UBP could also be achieved by simple price reductions. This means that the actual value from the new pricing model bases on the fact that both parties now share information on costs and demand, and use this information to jointly optimize c and n in the same way as an integrated company.

As a consequence, we find that UBP seems to provide no value on a purely operational level. This view, however, nevertheless falls short of understanding the importance of UBP to suppliers of smart products and their customers from a strategic perspective. As shown in equation (7), UBP implies a risk transfer from C to S, i.e. both parties share the risk of unexpected demand fluctuations in C's market beyond known stochastic influences. In the most extreme case (i.e. $f=0$), S carries all associated risks in their entirety. These risks are rather low in mature markets where demand patterns are sufficiently known and can be described by Φ, but tend to be significantly higher in emerging markets, which poses a critical challenge to C's business. In the latter case, UBP might become an important selling argument that helps lower initial barriers to invest in S's machines. Therefore, we come to the conclusion that UBP should most of all be regarded as a strategic tool to attract new prospects and to enter new markets, but only to a lesser extent as a means to keep existing customers.

SUMMARY AND OUTLOOK

The aim of this contribution was to investigate to what extent suppliers and users of smart products can draw quantifiable benefits from Usage-Based Pricing policies. For this purpose, we developed an analytical model of a supply chain to compare Usage-Based Pricing to a traditional scheme with fixed prices. The main conclusion that can be drawn from our research results is that on an operational level Usage-Based Pricing does not provide any additional value to the two parties that could not also be achieved by sharing information on demand and manufacturing costs, and joint price optimization. From a more strategic perspective, however, we find that the transfer of demand risk from the customer to the supplier implied by Usage-Based Pricing might be used as a strategic tool for entering emerging markets. In this case, Usage-Based Pricing decreases the customer's risk of unexpected demand fluctuations and, thus, lowers his barriers to invest in the supplier's machines.

The implementation of Usage-Based Pricing models in real-world settings is still in its infancy. The necessary technological foundation in the form of sensor-equipped products, however, is already available today in a variety of industries and application domains. Modern printing machines, for example, comprise several hundreds of sensors that allow for drawing detailed conclusions on product usage. Today, this information is used, among others, for the scheduling of maintenance and repair tasks, spare parts replenishment, and new product development. In the near future, manufacturers of printing machines might additionally use sensor data to offer new customers virtually risk-free trial periods that link payments not to time as under traditional leasing models but to actual usage. The managerial challenge herein will be to get the balance right between the potential increase in machine sales on the one hand and the risk of suffering from demand shifts in the customer's market on the other hand. Further candidates for future smart products include, for example, construction tools and high-value equipment in medical diagnostics.

With regard to further research opportunities, we see great potential in the analysis of sensor-based pricing models in other contexts. Examples of pricing schemes on the foundation of ubiquitous computing technologies can be found not only in the form of pay-per-use tariffs but also in the car insurance industry, where automatically collected information on driver behaviour and the associated risks can be used to calculate highly individualized insurance premiums (Woehr 2006). Another example is the emergence of so-called 'Performance-Based Logistics' contracts in military aviation, which link a customer's payments to the supplier of an engine, a weapon system, etc. to the equipment's actual availability (Cohen 2006). In all these application domains, it is necessary to develop an in-depth understanding of risks and benefits using a variety of research methodologies (e.g. mathematical modelling, case studies) to be able to support the decision maker in corporate practice.

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