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Decision Support

Optimal design of uptime-guarantee contracts under IGFR valuations and convex costs

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ABSTRACT

An uptime-guarantee contract commits a service provider to maintain the functionality of a customer's equipment at least for certain fraction of working time during a contracted period. This paper addresses the optimal design of uptime-guarantee contracts for the service provider when the customer's valuation of a contract with a given guaranteed uptime level has an Increasing Generalized Failure Rate (IGFR) distribution. We first consider the case where the service provider proposes only one contract and characterize the optimal contract in terms of price as well as guaranteed uptime level assuming that the service provider's cost function is convex. In the second part, the case where the service provider offers a menu of contracts is considered. Given the guaranteed uptime levels of different contracts in the menu, we calculate the corresponding optimal prices. We also give the necessary and sufficient conditions for the existence of optimal contract menus with positive expected profits.

1. Introduction

In many industries, the steady execution of value added activities depends on uninterrupted performance of sophisticated equipment whose maintenance must be outsourced. The imperfect reliability of critical equipment threatens the revenue stream of their owners. To hedge the risk of break downs, owners would be willing to pay premiums for services which increase the reliability of their equipment. On the other hand, faced by saturated markets and fierce competition, many traditional core manufacturing companies are reinventing their services as key sources of revenue (Sawhney, Balasubramanian, & Krishnan, 2003). When managed correctly, maintenance contracts can leverage customers' requirements for more reliable equipment and service providers' revenue diversification strategies.

A standard quality control indicator for determining the effectiveness of a maintenance service contract is the equipment's *uptime*, that is, the fraction of time that the device will be operational and ready to use (Chan, 2003). An *uptime-guarantee contract* commits a service provider to maintain functionality of some equipment at least for certain fraction of working time during a contracted period. In this sense, an uptime-guarantee contract is a special form of performance-based contracts (see Selviaridis & Wynstra, 2015 for a review). This paper addresses the optimal design of uptime-guarantee maintenance contracts.

This study is particularly motivated by the contracting practices in the high-tech medical equipment industry such as medical imaging devices. The annual maintenance service cost for a medical imaging device can be as much as 8.5 percent of the initial purchase cost and it has become a key competitive factor among different manufacturers (Sferrella, 2012). Not surprisingly, specific patterns of servitization can be observed among the manufacturers of medical technology (Schröter & Lay, 2014). Brunschot (2015) gives a detailed report on a major European manufacturer's attempts to systematically overhaul its uptime-guarantee contracts. Although contractual commitments on uptime are quite common with medical equipment (Mancino & Siachos, 2007), the research into maintenance service contracts in the health care sector is still in its infancy stages (Cruz & Rincon, 2012).

Among all the terms and conditions of an uptime-guarantee contract, we focus on two main features: the guaranteed uptime level and the price. The service provider's goal in designing an uptime-guarantee contract is to maximize his (expected) profit. While charging too high a price deters the customer from purchasing the contract, too low a price leaves the service provider at loss. The key to the optimal design of such contracts is understanding a customer's valuation of a contract which is the basis for her decision to purchase the contract or rely solely on corrective maintenance. The customer's valuation is considered to involve two terms: (a) expected utilization time, i.e., the amount of time that the customer can make use of the equipment given its

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uptime level, and (b) unit revenue rate, i.e., the revenue obtained by utilizing the equipment for a unit of time. In many cases, including our motivating scenario, the service provider has a very good understanding of the customer's utilization function—in light of standard warranty periods where the performance of the equipment is constantly monitored by the service provider. However, in almost all real life situations the service provider does not have the exact information about the customers' unit revenue rates. We assume that the service provider knows the distribution of the customer's unit revenue rate. As a technical requirement for tractability we assume that the customer's unit revenue has an Increasing Generalized Failure Rate (IGFR) distribution function. Many well-known distribution functions satisfy the IGFR condition, e.g., exponential, normal, logistic, Weibull, gamma, beta, Cauchy, etc. (Banciu & Mirchandani, 2013). The IGFR distribution assumption is common in supply chain revenue management and pricing literature (Lariviere, 2006).

In the first part of this paper, we consider the case where the service provider offers a single contract to the customer. We focus on contracts which are interesting from the perspective of both parties. That is, we search for a contract that has a positive chance of being purchased by the customer and generates a positive profit for the service provider. As we show, the existence of such a contract can be ensured by enforcing a condition on the guaranteed uptime level. We then develop closed-form formulas for the optimal price as well as the optimal guaranteed uptime level. In doing so we assume that the service provider's cost function for providing contracts with different uptime levels is convex, that is, guaranteeing higher uptime levels are increasingly costly.

The second part of the paper extends the analysis to situations where the service provider offers menus of contracts. A contract menu enables the service provider to extract more profit from a customer with high valuation without risking the potential profit that can be obtained from a customer with low valuation. Given the guaranteed uptime levels of the contracts in a menu, we optimize their corresponding prices to maximize the expected profit from the contract menu. We provide the necessary and sufficient conditions on the guaranteed uptime levels that ensure the existence of optimal contract menus with positive expected profits.

The rest of this paper is organized as follows. Section 2 overviews the previous relevant studies in the literature. Section 3 outlines the elements of our mathematical model. The design of singular contracts is discussed in Section 4. The analysis of contract menus is carried out in Section 5. Section 6 concludes the paper. All proofs are presented in the Appendix.

2. Literature review

We overview the literature on maintenance contracts. A number of papers in this domain focus on either customer' or service providers' decision problems. In a multi-criteria decision making framework, de Almeida (2001) investigates a customer's optimal choice from a given set of contracts by incorporating their risks, costs, and other consequences on the performance of equipment. Wang (2010) emphasizes on the interplay between inspections and repair services. Assuming fix contract prices, he analyzes the relationship between an equipment owner's choice of contract and inspection intervals offered by a service provider.

Several papers in the literature study the design of optimal service contracts drawing upon the Stackelberg game while making the critical assumption that all information is commonly known by the parties involved. Murthy and Yeung (1995) discuss the optimal strategies for a customer and a service provider with two types of maintenance services: pre-planned and immediate. The optimal contract prices are calculated based on the customer's unit revenue rate of workable equipment time. Murthy and Asgharizadeh (1999) and Ashgarizadeh and Murthy (2000) study the optimal decisions of one or more equipment owners and a service provider in terms of right choices of contract, contract prices, and service channels. Rinsaka and Sandoh (2006) extend the work of Murthy and Asgharizadeh (1999) to the time after the initial warranty period. Within a multi-stage decision making framework, Hartman and Laksana (2009) examine the optimal strategies for equipment owners with regards to the types of extended warranty contracts as well as pricing policies. They show that by offering multiple contracts a service provider can dramatically increase its profit. Tong, Liu, Men, and Cao (2014) discuss the pricing strategies for a provider of two-dimensional warranty contracts. Esmaeili, Gamchi, and Asgharizadeh (2014) study the choices of various attributes in a three-level warranty service contract among a manufacturer, a service provider and a customer. Gallego, Wang, Hu, Ward, and Beltran (2014) analyze the residual value extended warranty contracts where a customer would receive a bonus if no claims are made during the term of contract. They study the pricing problems associated with single and menu contracts for strategic customers with different risk attitudes.

Although the Stackelberg game is the most common approach taken in the literature, few authors use cooperative and/or bargaining games to study the design of maintenance contracts. Hamidi, Liao, and Szidarovszky (2014) analyze a two-player cooperative game with an equipment owner, who announces the time of replacement of a part, and a service provider, who chooses the order time of the part. Jackson and Pascual (2008) consider a negotiation scenario where contract prices, preventive maintenance intervals, and response times are set to equally divide the profits between an equipment owner and a service provider.

Another stream of research underlines the fact that interacting parties may not be fully aware of each other's attributes. Taking into account the indeterministic nature of customers' attitude to risk, Huber and Spinler (2012) formulate a model which allows a service provider to manage his revenue by setting the prices of full-service or on-call maintenance contracts. They give a closed-form formula for the service provider's optimal contract prices under the assumption that the customer's attitude toward risk is uniformly distributed. Huber and Spinler (2014) extend the latter model to account for learning, optimized maintenance, and information asymmetry between customers and service providers. In an alternative setting where customers design the maintenance contracts, Kim, Cohen, Netessine, and Veeraraghavan (2010) introduce contractual structures that mitigate service providers' moral hazards associated with their capacity investments. Zeng and Dror (2015) extend the analysis of this problem in several directions.

Another approach to managing the relationship between customers and service providers seeks to coordinate the parties' efforts to optimize the system-wide profit—as opposed to focusing on either customers' or service providers' decision making problems. Within a deterministic framework, Tarakci, Tang, Moskowitz, and Plante (2006a, 2006b) analyze several mechanisms, including a pricing scheme for maintenance contracts, to ensure that the optimal intervals for preventive maintenance from the perspectives of both service provider and equipment owner coincide. Tseng and Yeh (2013) extend the single processor case discussed in Tarakci et al. (2006a) for risk-averse customers.

Instead of relying on game theory to analyze the interactions between agents involved, some authors build models that use demand elasticity to capture the effects of contracts with different terms and conditions on service providers' profit. Drawing upon a non-linear deterministic demand function for approximating customers' sensitivity to contract price and delivery time, So and Song (1998) propose a model to analyze pricing, delivery time guarantee and capacity expansion decisions of a service provider. In a holis-