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On Contractual Periods in Supplier Development

Karl Worthmann * **Philipp Braun** ** **Michael Proch** *** **Jörg Schlüchtermann** *** **Jürgen Pannek** ****

* *Institute for Mathematics, Technische Universität Ilmenau, 98693 Ilmenau, Germany (e-mail: karl.worthmann@tu-ilmenau.de)*
** *Mathematical Institute, University of Bayreuth, 95440 Bayreuth, Germany (e-mail: philipp.braun@uni-bayreuth.de)*
*** *Faculty of Law, Business Administration and Economics, University of Bayreuth, 95440 Bayreuth, Germany (e-mail: {michael.proch, j.schluechtermann}@uni-bayreuth.de)*
**** *Dynamics in Logistics, BIBA, University of Bremen, 28359 Bremen, Germany (e-mail: pan@biba.uni-bremen.de)*

Abstract: We consider supplier development within a supply chain consisting of a single manufacturer and a single supplier. Because supplier development usually requires relationship-specific investments, firms need to protect themselves against partner opportunism. Even though contracts are viewed as the primary formal means of safeguarding transactions, they also entail certain risks, e.g., a lack of flexibility, particular in a dynamic and uncertain business environment. Thus, we propose a receding horizon control scheme to mitigate possible contractual hazards while significantly increasing the overall supply chain profit. Our findings are illustrated by a numerical example.

Keywords: Supply chain management, supplier development, optimal control, predictive control, dynamic systems.

1. INTRODUCTION

Since manufacturing firms increasingly focus on their core competencies, an efficient supply chain plays a paramount role in generating competitive advantage. In response, manufacturers across a wide range of industries are implementing supplier development programs to improve supply chain performance, see Wagner (2010). Supplier development is broadly defined as *any effort by a buying firm to improve a supplier's performance and/or capabilities to meet the manufacturing firm's short- and/or long-term supply needs*, cf. Krause (1999, p. 206), and has been applied in various fields of application with a particular focus on automotive supply chains, see, e.g., Talluri et al. (2010); Krause and Scannell (2002).

Because resources committed to supplier development activities are difficult or even impossible to redeploy and thus have little or no value in an alternative use, firms need to safeguard the respective investments against the hazards of partner opportunism, see Wang et al. (2013). Previous research has shown that contracts are viewed as the primary formal means of protecting transactions, see, inter alia, Lui et al. (2009); Artz (1999). The drawback of formal contracts is, as the degree of uncertainty increases, both specifying ex ante all possible contingencies and verifying ex post the performance of the supply chain partner become increasingly difficult, cf. Williamson (1979). Therefore, supply chain partners may be reluctant to sign long-term contracts, which potentially diminishes the firms' propensity to invest in supplier development activities and thus impedes the manufacturer's initial strategy to enhance supply chain performance, see Rokkan et al. (2003).

Even though empirical studies support the notion that relationship-specific investments are critical to the success of supplier development, see, among others, Wagner (2011); Krause et al. (2007), the application of formal decision-making models proposed for assisting firms in contract negotiations in order to adequately safeguard such investments have received limited attention in the supplier development literature. Without understanding the impact of the contract period on the firms' willingness to commit relationship-specific resources to supplier development, its return will be negligible, perhaps even leading to the premature discontinuation of such collaborative cost reduction efforts.

Given this background, the purpose of our research is to mitigate possible contractual hazards while significantly enhancing the supplier development process, and thus increasing the overall supply chain profit. Thus, the contribution of this paper is twofold: First, we investigate the impact of the contract period, i.e., the *planning horizon*, on the firms' propensity to commit relationship-specific resources to supplier development and show that the firms' willingness to participate in supplier development critically depends on the length of the planning horizon. Secondly, given the fact that long-term contracts entail certain risks, e.g., a lack of flexibility, we propose a receding horizon control scheme and show that the supplier

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development process can be enhanced by dynamically extending the contract, i.e., the firms are not contractually tied for unnecessarily long periods of time, see Sethi and Sorger (1991) for the basic idea of prediction based control. Here, we present a strategy that optimally balances costs and benefits of supplier development.

The paper is structured as follows. In Section 2 the mathematical model is described. This allows to study the dependence of the control policy on the contract period in the subsequent section. In Section 4, a receding horizon control scheme is proposed and analysed before the effectiveness of the developed methodology is demonstrated by means of numerical investigations in Section 5. Finally, conclusions are drawn in Section 6.

2. MODEL DESCRIPTION

We consider a supply chain consisting of a single manufacturer and a single supplier. In doing so, the decision-making process is structured such that the manufacturer M determines the quantity supplied to the (oligopolistic or monopolistic) market solely based on the leitmotif of profit maximization — without taking the outcome for the supplier S into account. Herein, we restrict ourselves to the linear price-distribution curve $p(d) = a - bd$ in order to streamline the upcoming analysis.

2.1 Basic model

It is supposed that the supplier wants to earn a constant revenue r per unit. Thus, the manufacturer's supply costs are $c_{SC} = r + x(t)^m c_0$, $\dot{x}(t) = u(t)$ with $x_0 = 1$, where the supplier's production costs per unit are modelled by $x(t)^m c_0$ depending on the learning rate $m < 0$. This means that the overall production costs may be reduced by using the control function $u \in \mathcal{L}^\infty(\mathbb{R}_{\geq 0}, [0, \omega])$ and, possibly, to increase the supply chain profit. Here, the measurable and bounded function u describes the effort invested in supplier development, e.g., by realizing inter-organizational projects. This component mimics a learning curve, cf. Yelle (1979).

The fact that increases in productivity do not typically come for free is reflected by a penalization term $c_{SD}u(t)$ that allows for integrating the costs of supplier development efforts into the proposed model. Overall, this yields the supply chain's profit function $J_T^{SC} : u \mapsto \mathbb{R}$

$$J_T^{SC}(u; x_0) := \int_0^T \frac{(a - c_M - c_0 x(t)^m)^2 - r^2}{4b} - c_{SD} u(t) \, \mathrm{d}t \tag{1}$$

during the contract period $[0, T)$ neglecting fixed costs, see Table 1 for an explanation of the individual parameters. We emphasize that investments into the cost structure of the supply chain are economically reasonable as long as these amortize during the runtime of the contract. For a detailed derivation of the model in consideration the interested reader is refered to Kim (2000).

2.2 Solution of the Optimal Control Problem

Analogously to Kim (2000), using Pontryagin's maximum principle, see, e.g. Lee and Marcus (1967), yields that

Symbol	Description	Value
T	Contract period	60
a	Prohibitive price	200
b	Price elasticity	0.01
c_M	Variable cost per unit (M)	70
c_0	Variable cost per unit (S)	100
r	Revenue per unit (S)	15
c_{SD}	Supplier development cost per unit	100000
ω	Maximal investment rate	1
m	learning rate	-0.1

Table 1. List of Parameter

the control function $u^\star : [0, T) \to [0, \omega]$ maximizing (1) exhibits the structural property

$$u^\star(t) := \begin{cases} \omega & \text{if } t < t^\star \\ 0 & \text{if } t \geq t^\star \end{cases} \tag{2}$$

depending on the (optimal) switching time $t^\star \in [0, T]$. The switching time $t^\star$ is characterized by the equation

$$\frac{mc_0(x_0 + \omega t^\star)^{m-1}(a - c_M - c_0(x_0 + \omega t^\star)^m)}{2b} = \frac{c_{SD}}{(t^\star - T)}. \tag{3}$$

In the following, (3) is called switching condition. Indeed, it can be easily shown that this condition is necessary and sufficient for the considered problem since the cost function is (strictly) convex and the system dynamics are governed by a linear ordinary differential equation.

Summarizing, the optimal value $V_T(x_0)$ of the problem in consideration is attained by

$$V_T(x_0) := \sup_{u \in \mathcal{L}^\infty([0,T),[0,\omega])} J_T^{SC}(u; x_0)$$

where the expression on the right hand side is maximized subject to $\dot{x}(t) = u(t)$, $x(0) = x_0$. Since $V_T : \mathbb{R}_{\geq 1} \to \mathbb{R}$ maps the initial state x_0 to the optimal value, V_T is called optimal value function. The index T indicates the length of the contract period and can be considered as a parameter — an interpretation, which is crucial for the upcoming analysis.

Evidently, investments (in the cost structure) pay off in the long run, i.e., all the effort is spent directly at the beginning of the collaboration. Then, the resulting cost decreasing effect is exploited during the remainder of the contract period $[0, T]$.

Remark 1. At the switching time $t^\star$ the marginal revenue (given by the adjoint variable λ) equals the marginal costs (given by c_{SD}) as indicated in Figure 1. This reasoning explains the meaning of the switching condition (3).

3. DEPENDENCE OF THE OPTIMAL SWITCHING TIME ON THE CONTRACT PERIOD

The contract between the manufacturer M and the supplier S ranges over the interval $[0, T]$. Realistically, two cases can be distinguished: on the one hand, a relationship-specific investment reducing the supply costs does not pay off during the contract period — resulting in the (optimal) switching time $t^\star = 0$, i.e., supplier development is economically not recommendable. On the other hand, $t^\star > 0$ stands for the scenario where investing into supplier development amortizes until T.

From the specific structure (2) of the optimal control function it can be concluded that this claim holds for all