



# Information Asymmetry in Business-to-Business Negotiations: A Game Theoretical Approach to Support Purchasing Decisions with Suppliers

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## Abstract

The digital transformation confronts purchasing and supply management (PSM) with numerous new challenges, such as digital procurement objects and the information asymmetry between buyers and suppliers. Existing approaches contributing to PSM research (e. g., the selection of suppliers or the calculation of equilibrium prices) have in common that information regarding suppliers (e. g., production costs) must be well-known. However, this information is rarely accessible to purchasers due to the existing information asymmetry. This problem is addressed by a game-theoretical model based on a Stackelberg game to assist PSM in dealing with the information advantage of software suppliers. The applicability in practice is evaluated by a real-world case study from the automotive industry. The results show that the presented model can support decision-making in purchasing by a qualitative analysis of profit scenarios for different negotiation strategies. The model contributes to dismantling the information asymmetry and provides a basis for determining negotiation prices, also for digital procurement objects. This research motivates both supply and purchase managers to jointly optimize their product costs and thus increase their competitiveness on the market.

**Keywords** Game theory · Information asymmetry · Decision support · Negotiation · Supply management · Cost management

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## 1 Introduction

One of the claims made by proponents of the Internet is that it will create transparency through wider information sharing. Pressure groups, governments (at both national and regional levels), and customers are aware of the “democratic” principles inherent in the concept of transparency. In purchasing and supply management, transparency has largely been viewed as an additional (but perhaps ultimately the most significant) pressure on margins. According to Vosooghizaji et al. the difficulty for purchasing managers lies in aligning individual decisions with the overall corporate objectives, since the decisions are usually accompanied by a high degree of information asymmetry between supplier and customer (Vosooghizaji et al. 2020). In general, information asymmetries are a problem when reliable information is needed to make better decisions. For example, in contract decisions, if the supplier has private information about the efficiency of his production processes, the buyer will have difficulties in determining a price and purchase quantity (Bodendorf et al. 2020). As a result, management often accepts higher prices for smaller purchase quantities, what may lead to less innovation investments on the supplier side and is therefore problematic in the long run, as Ni et al. (2020) explain. As Johnson et al. describe, procurement managers believe that the supplier should be paid a “fair” price. But what is a “fair” price? For the buyer, it will be the lowest possible price that guarantees a continuous supply of the right quality at the right time and place. For the supplier, the total costs incurred should be covered and a profit should be made (Johnson et al. 2016).

This research is motivated by the above-mentioned challenge of information asymmetry in the purchasing and supply chain business. The business relationship between suppliers and their customers is characterized by a great information asymmetry regarding the development costs of digital goods, especially containing software components. This frequently leads to so-called principal-agent conflicts with problems of adverse selection and moral hazard. (Baron and Besanko 1987).

This challenge is particularly evident in negotiations with suppliers in the purchasing of digital products (Bodendorf et al. 2021a). Negotiations basically have an integrative and dynamic information character (Reiser 2013). The parties involved usually start with different levels of information and different goals. They have the intention to share information, except for the ones they consider worth protecting (Reiser 2013). For software suppliers, the development effort represents information worth protecting, and they expect to gain a negotiating advantage from withholding it. They can use their knowledge advantage to make the customer dependent, to bind him to their company or to enforce a price that is advantageous for them.

However, the client has several options to reduce information asymmetry, e.g., through information management, data accuracy, and monitoring instruments. (van Thiel 2016; Hsu et al. 2008; Mithas et al. 2011).

One crucial monitoring measure is cost management in purchasing (Bodendorf et al. 2022; Kulmala 2004). Cost analysis and the resulting prediction models are

a central instrument of this process (Bodendorf et al 2021b). "By [the] supply of calculations, e.g., with the evaluation of concepts, technology alternatives and change costs" the specialized buyer is to be supported with negotiations and the selection of suppliers (Kajüter and Kulmala 2005). Digital procurement objects pose new challenges for cost analysis due to their special cost structure. For material goods, in general the material input and the individual production steps are analyzed. In the case of digital components, such as software, this does not lead to a useful result due to their cost structure consisting of high fixed costs for development and variable costs tending towards zero. Consequently, in the context of increasing digitization, new methods are needed to reduce information asymmetries in the supply chain by evaluating prices and costs (Boehm et al. 2000; Jorgensen and Shepperd 2006; Bodendorf et al. 2021a).

Game theory represents a promising approach for this purpose. Strategic decision-making situations where individual interests of several people meet can be transformed into simplified, formalized models, so-called games (Başar et al. 2018). The different information levels of the actors can be considered (Geckil and Anderson 2016). The primary goal of game theory is to use these models to determine recommendations for action for all actors involved, i.e. the players, to provide decision support in complicated situations (Matsumoto and Szidarovszky 2016). However, game theory is also used to explain observed events and predict actions (Kolmar 2017). Consequently, the objectives of game theory overlap with those of cost analysis, which supports purchasers in their decision making with recommendations for action as well as cost forecasts and assessments.

Game theory has already been used to support the procurement in the selection of suppliers. Liu et al. for example integrate for their model of comprehensible supplier selection besides the game theory different approaches like the evidence theory, ANP (Analytic Network Process), entropy weight and DEMATEL (Decision-Making Trial and Evaluation Laboratory). The systematic method for efficient supplier selection has high extensibility and can also process large amounts of data to reduce the risk of poor investment decisions. However, the model does not consider possible information asymmetries regarding production costs. (Liu et al. 2018).

Furthermore, game theory is used to analyze and improve the performance of supply chains. Li and Nagurney introduce for this purpose a performance measurement model for a multi-level supply chain network. In particular, the importance of individual suppliers and components for the success of the entire supply chain is examined. The authors present a comprehensive list of importance indicators for evaluating the significance of suppliers and their components for the performance of the entire supply chain, which is a valuable decision-making aid for planning and investment projects in supplier management (Li and Nagurney 2017). The focus of the study by Deljavan and Sadeghi is on improving the competitiveness of suppliers and thus the entire supply chain. Previous models, which only depict supply chains with two suppliers, are extended to an n-supplier Stackelberg game, in which any number of suppliers can be considered. Unlike similar models, customer satisfaction is also considered. The model is tested using a case study within an automotive company in Iran (Deljavan and Sadeghi 2012). Sadjadi et al., on the other hand, look at the effects of strategic customer behavior in

a supply chain consisting of a supplier and a retailer. To this end, they first use a Stackelberg game between supplier and retailer to determine the equilibrium wholesale price and equilibrium production quantity. In a second step, the retailer's equilibrium pricing strategy and the customers' equilibrium purchasing strategy are determined in a non-cooperative game. The model considers both vertical and horizontal relationships between suppliers, retailers, and strategic customers, providing valuable knowledge for supply chain management. (Sadjadi et al. 2016). All these game theoretic models can help purchasing and supply chain management to improve supply chain performance. However, they do not address common information asymmetries in the supply chain that often negatively affect its performance.

Game theory, nevertheless, has been successfully applied to study information asymmetries in buyer–supplier relationships. Kim and Netessine, for example, use a game theory model to analyze how information asymmetry between a buyer and supplier affect supply chain members' incentives to collectively reduce costs. To this end, the model formalizes the process of collaboration between buyer and supplier in cost reduction. In doing so, the authors consider numerous aspects such as the dynamics of cooperation and joint decision-making under adverse selection and moral hazard caused by demand and cost uncertainty. However, the resulting complex model is based on many assumptions, some of which can be relaxed to provide further insights (Kim and Netessine 2013). Yin et al. analyze supply chains using Stackelberg games. The goal is to support manufacturers in dealing with uncertain demand and asymmetrical information about the quality level. By determining optimal production and procurement quantities, material prices and optimal product quality, the coordination of the supply chain can be improved (Yin et al. 2013). However, asymmetric production cost information is not considered.

Negotiations are the core of the buyer-supplier relationship and particularly affected by any information asymmetries that may arise between buyer and supplier (Ribbnik et al., 2014). Chen et al. investigate in this context the behavior of a buyer and two competing suppliers in simultaneous negotiations from the buyer's perspective in a Stackelberg game to determine the extent to which the buyer's negotiation policy and the suppliers' strategies regarding the disclosure of their production cost information affect the financial success of the respective actors (Chen et al 2004; Chen et al. 2019).

The approaches considered provide valuable insights into various supply chain management and purchasing challenges, including the impact of information asymmetries. However, most of them do not explicitly examine or estimate supplier costs and are therefore unsuitable to support the cost analysis of digital products in purchasing.

The game theoretical approaches of Deljavan and Sadeghi et al., Yin et al. and Chen et al., on the other hand, are interesting for this application area, because they calculate the profit-maximum equilibrium prices for all players. These results can be used to evaluate the supply prices of software products and to reduce the information advantage of software suppliers with respect to development costs. All these approaches have in common that for the calculation of the equilibrium prices the production costs of the regarded product must be known. However, purchasing and

supply managers do not know the level of production costs of digital goods, which mainly consist of their development costs.

This contribution addresses this problem by a game theory based cost analysis model. It focuses on the theoretical “why” and the practical “how” game theory can support PSM in price negotiations of intangible goods characterized by a high degree of information asymmetry between manufacturer and supplier. This model first anticipates the production costs of the considered digital product with the help of a technology-oriented analogy method. Subsequently the price negotiations between a buyer and two competing software suppliers are analyzed with the help of a Stackelberg game. The development of the model is described in Sect. 2. It is applied and analyzed in a use case using real world data coming from the automotive industry in Sect. 3. Based on this, the strengths, and weaknesses as well as possible improvement measures of the developed approach are discussed in Sect. 4.

## 2 Game Theory Based Cost Model

The center of the developed model is the analysis of price negotiations, as an interactive price mechanism, within a supply chain involving a buyer and two competing software suppliers in a Stackelberg game. This is a sequential game, characterized by a leader–follower hierarchy. A Stackelberg game is solved by reverse induction. Each stage of backward induction can be considered as a separate simultaneous subgame with its own Nash equilibrium (Alkan et al. 1983; Vasnani et al. 2019). The relationships between the game theoretical analysis and the other components of the model are shown in Fig. 1 and explained below.

The buyer acquires identical, digital products from both suppliers, which differ only in their production costs, and resells them to the end customers. With the help of a two-stage Stackelberg game the optimal negotiation strategies of all players are determined under asymmetrically distributed production cost information. In practice, it is difficult for purchasing managers to assess the level of information asymmetry regarding the software supplier. The procurement as a buyer does not know to what extent the suppliers behave opportunistically or cooperatively. For this reason, in the context of the model the information asymmetry is considered only in relation to the production costs of the suppliers. It is assumed that the buyer is fully aware of the suppliers’ costs or has no knowledge of their costs at all.

The maximum profits of the participants for eight different scenarios, which result from their strategy choice, are estimated. By comparing the winnings of the players, strategic recommendations for purchasing can be derived to reduce the existing information asymmetry. The buyer can choose a uniform or segmented negotiation strategy. In the first case, the buyer bargains a uniform wholesale price for the digital products together with both software suppliers in one negotiation. In this case the buyer pays the same price to both suppliers. With a segmented negotiation strategy,

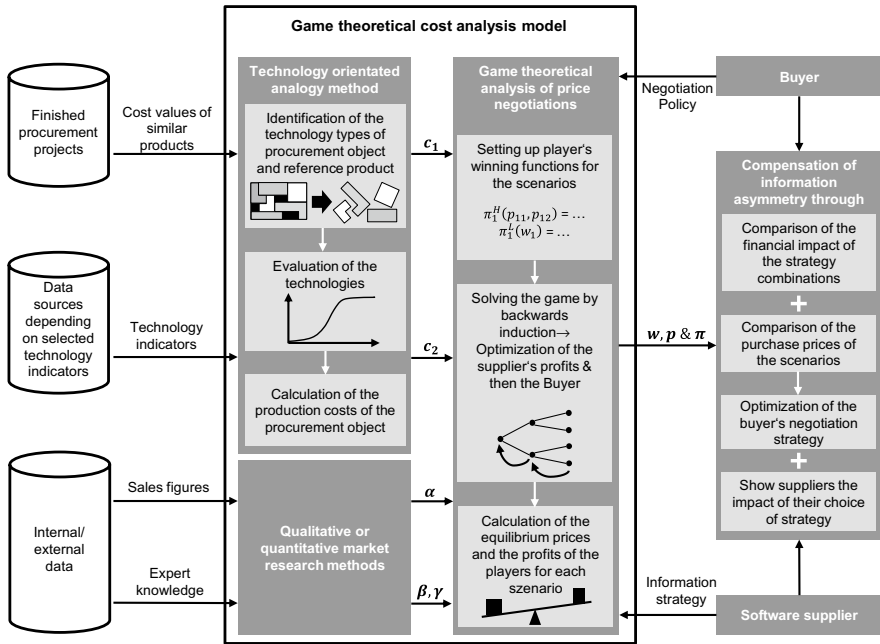


Fig. 1 Conceptual structure of the game theory-based model for cost analysis

on the other hand, the buyer negotiates different wholesale prices with both suppliers in two separate negotiations. The software suppliers choose whether to share or withhold information with the buyer on the actual level of their production costs, which in the case of digital goods mainly consist of their development costs.

To be able to calculate the profits of the eight scenarios derived from these strategy options, first the production costs of the suppliers, the market potential of the digital product under consideration, as well as the intrinsic and cross-price elasticity of the product must be determined. Production costs are estimated with the help of a technology-oriented analogy method. This method uses historical cost data from comparable procurement objects.

### 2.1 Assessment of Production Costs

Production costs can be estimated, for example, with the help of data from the supplier portal and tendering system ASTRAS (Allocation STRategic e-Sourcing). This software serves as a data platform on which all available supplier information is visible (Allocation Network GmbH 2020).

The adjustment of cost values of similar products is based on the performance potential of the relevant technologies the reference product and the similar product are built on. This is done by "the analysis of the functional-abstract solution principles that are incorporated in [...] [this]" (Hartmann 2008). The future performance

potential of the technology types of both products is evaluated based on their position on the technology S-curve according to McKinsey by a technology attractiveness score of zero to four (Hartmann 2008; Bodendorf and Franke 2020). The assignment of the technology attractiveness values to the respective technology classes and the transition phases is shown in Fig. 2.

For the evaluation of technologies and their positioning on the S-curve various indicators are available. A detailed procedure for technology assessment as well as indicators for technology evaluation can be found in the guidelines of Eppinger et al. (Eppinger et al. 2017).

Once the technology attractiveness of the respective technology types are determined for the reference product and the similar product, the overall technology attractiveness of each product is calculated (Hartmann 2008):

$$GTA = \sum_{i=1}^n TA_i \tag{1}$$

- $n$  Number of technology types of the product
- $TA_i$  Technology attractiveness of technology type  $i$
- $GTA$  Overall technological attractiveness of the product

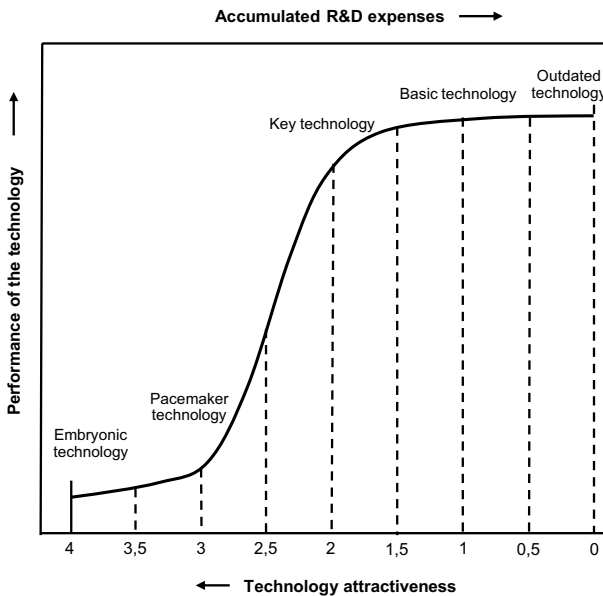


Fig. 2 Attractiveness and performance of technologies

The known cost of the reference product is compared to its overall technological attractiveness, which reflects its future performance potential. It is assumed that this ratio can be transferred to the new procurement object. The target technology costs of the procurement object can be calculated by:

$$c_B = \frac{c_V}{GTA_V} GTA_B \quad (2)$$

$c_B$	Target technology costs of the procurement object
$GTA_V$	Overall technology attractiveness of the reference product
$c_V$	Total cost of the reference product
$GTA_B$	Overall technological attractiveness of the procurement object

This approach assumes that higher costs are justified for young technologies whose future performance potential is estimated to be stronger than for basic technologies whose performance potential has already been exhausted (Hartmann 2008). Thus, higher costs are assumed for the new procurement object compared to the costs of the reference product if it uses more innovative technologies than the reference product (see Fig. 2).

## 2.2 Price Negotiation Modelling Based on Game Theory

In the following, a game theoretical model for the analysis of price negotiations between a buyer and two competing software suppliers is presented. With the help of this approach, formulas for the equilibrium prices and the maximum winnings of the players can be determined for all possible scenarios. By inserting values of production costs, market volume and price elasticities into the formulas of the model, recommendations for negotiation actions can be derived, looking at the maximum profits of the players for the different scenarios.

In the model the buyer acts as a leader of the Stackelberg game and the two software suppliers as followers. The supplier  $i$  produces the product  $i$ . Both products can be regarded as substitutes. The suppliers differ only in their production efficiency. Supplier 1 produces with lower production costs than supplier 2:

$$c_1 < c_2 \quad (3)$$

$c_1$	Production costs from software supplier 1
$c_2$	Production costs of software supplier 2

The buyer purchases products from both suppliers at the wholesale prices  $w_1$  and  $w_2$  and resells them to the end customers at the retail prices  $p_1$  and  $p_2$ . Due to the very low probability that both suppliers have the same production efficiencies, the



case  $c_1 = c_2$  is not examined in more detail. It is assumed that the players involved behave rationally and seek to maximize their profits.

The extensive game consists of two levels and can be represented by the game tree shown in Fig. 3. In the first stage, at node A, the buyer, as leader, chooses one of the two negotiation policies available to him to negotiate wholesale prices with suppliers. If the buyer chooses a uniform negotiation policy, the buyer negotiates a uniform wholesale price with both software suppliers simultaneously based on their respective production costs.

$$A_K = \{ \text{“uniform negotiation policy”}, \text{“segmented negotiation policy”} \} \quad (4)$$

$A_K$  Action possibilities of the buyer.

If the buyer chooses a uniform negotiation policy, a uniform retail price is negotiated with both suppliers simultaneously based on their respective production costs.

$$w_1 = w_2 = w \quad (5)$$

- $w_1$  Wholesale price for software supplier 1
- $w_2$  Wholesale price for software supplier 2
- $w$  Single wholesale price for both suppliers

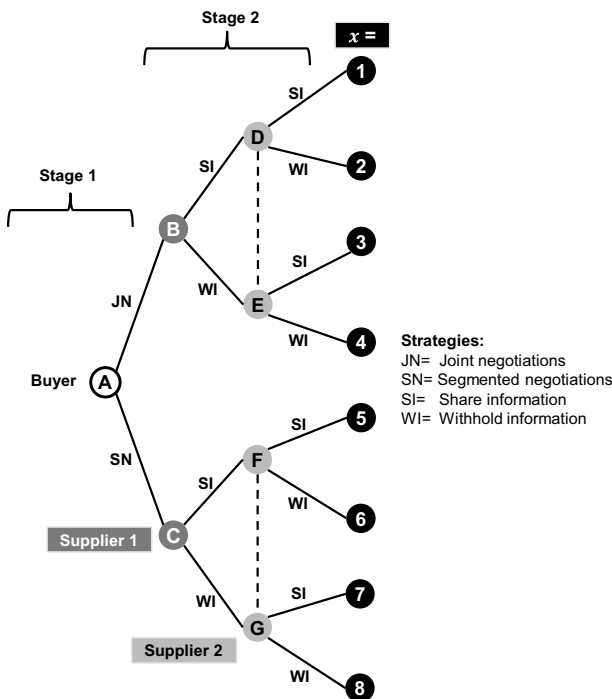


Fig. 3 Game tree of the negotiation game

On the other hand, if the leader decides to negotiate different wholesale prices with both suppliers separately, this is called a segmented negotiation policy.

In the second stage of the game, the suppliers choose their strategies for sharing their private information about their respective production costs. They have the following options for action:

$$A_{L1/L2} = \{\text{"Pass on production cost information"}, \text{"Withhold production cost information"}\} \quad (6)$$

$A_{L1/L2}$  Action options for supplier 1 and 2.

Supplier 1 chooses either at node B or C, depending on how the buyer has chosen. The game decomposition of supplier 2 includes nodes D to G. However, Nodes D and E as well as Nodes F and G are in the same information set of supplier 2:

$$I_{L2} = \{I_{L2,1}, I_{L2,2}\}; I_{L2,1} = \{D, E\}; I_{L2,2} = \{F, G\} \quad (7)$$

$I_{L2}$  Distribution of information from supplier 2

$I_{L2,1}, I_{L2,2}$  Information quantities from supplier 2

So, the supplier cannot determine at which of the two nodes the supplier is located. It is known how the buyer has chosen, but not which choice supplier 1 has made. It therefore does not matter whether supplier 1 or 2 is first in line.

The strategy option results in eight possible strategy combinations and thus eight scenarios in which the game can end (see Table 1 and Fig. 3). From the buyer's perspective, the degree of information asymmetry cannot be evaluated, as already explained. Due to the therefore simplified consideration of information asymmetry (suppliers share their production costs with the buyer or not), it is assumed that the probability of occurrence of the scenarios is equal.

The benefit of the players is defined by means of a profit function from the buyer's point of view. The profit functions are based on a conventional demand function for product  $i$ , which can be found in the supplemental file (A) (Choi 1992). The

**Table 1** Possible Negotiation Scenarios

Scenario $x$	Description
1	Joint negotiations and both suppliers disclose their cost information
2	Joint negotiations and only supplier 1 discloses its cost information
3	Joint negotiations and only supplier 2 discloses its cost information
4	Joint negotiations and both suppliers withhold their cost information
5	Segmented negotiations and both suppliers disclose their cost information
6	Segmented negotiations and only supplier 1 discloses its cost information
7	Segmented negotiations and only supplier 2 discloses its cost information
8	Segmented negotiations and both suppliers withhold their cost information

profit function is modelled differently for the supplier and the buyer depending on the chosen strategy combination. If the buyer decides on a segmented negotiation policy, different wholesale prices  $w_1$  and  $w_2$  are negotiated for the software suppliers and considered in the profit functions. In contrast, in case of a uniform negotiation policy, a wholesale price  $w$  is fixed and included in the profit functions. If the suppliers disclose their production costs, their actual costs  $c_1$  and  $c_2$  are used in the profit function. However, if they decide to withhold this information, negotiations are based on the average costs of the industry. In the present model, these are calculated in a simplified way using the average costs of the two suppliers ( $\frac{c_1+c_2}{2}$ ), since estimating the average costs of the industry considering many suppliers of the product under investigation and the data procurement required for this would be very time-consuming and complex. However, it is assumed that the buyer is not aware how the average costs of the industry are calculated.

In addition, the marginal profit  $m_{xi}$  of the buyer is used to calculate the profits of the software suppliers:

$$m_{xi} = p_{xi} - w_{xi} \quad (8)$$

- $m_{xi}$  Marginal profit of the buyer for product  $i$  in scenario  $x$
- $p_{xi}$  Retail price for product  $i$  in scenario  $x$
- $w_{xi}$  Wholesale price for product  $i$  in scenario  $x$ .

All the actors' profit functions for the relevant scenarios can be found in the supplemental file (B).

The equilibrium prices for the respective scenarios are determined by backward induction, as is usual for Stackelberg games. These calculations are based on the players' profit functions for the different scenarios. The equilibrium prices thus result from the players' choice of strategy. The prices are listed in the supplemental file (C, D). The detailed derivations of the formulas can be found in Chen et al. (2019). These prices are then used to determine the optimal profits of the players for all scenarios.

On the one hand, the game theoretical analysis of the price negotiations makes it possible to compare the calculated equilibrium prices of the different scenarios and thus to determine the optimal prices for the procurement of digital goods. On the other hand, software suppliers can be shown the financial consequences of their production cost information strategy and thus the positive effects that may result from the dissemination of their private cost information. The game theoretical model thus increases the information transparency in price negotiations with suppliers of digital goods and enables the buyer to optimize strategic decisions, coping with the existing information asymmetry.

### 3 Use Case Application

The developed negotiation model is applied to a practical real-world use case from the automotive industry to evaluate its usability for PSM of digital goods in purchasing. The price negotiations between an automobile manufacturer and two potential software suppliers are examined. The game theoretical model is applied from the perspective of the automobile manufacturer.

The negotiation between the car manufacturer and the software suppliers can be illustrated using the game tree of Fig. 3. The manufacturer acts as the buyer, that chooses its negotiation strategy in the first stage of the game. In the second stage of the game, the suppliers decide regarding the disclosure of their private information on the production costs of the products under consideration.

Connected cars assist drivers by IT and communication technologies and by so-called infotainment systems. These are integrated systems that combine state-of-the-art software and hardware to ensure a safe and comfortable driving experience for the driver and passengers. They provide various services such as navigation, assistance functions, news, and weather information or multimedia content (Reshma and Chetanaprakash 2020). Among others, the Real Time Traffic Information (RTTI) service is offered. It also calculates expected delays and suggests alternative routes (Moller and Haas 2019). It is assumed that for the RTTI procurement object two final, eligible software suppliers have already been selected to participate in the negotiations. It is also assumed that the rollout of the infotainment service will only take place on the German market. A contract for the provision of the RTTI system from January 2022 for a total of 5 years must be concluded with the supplier that will ultimately be awarded the contract.

In the next section, the application of the technology-oriented analogy method for calculating the suppliers' production costs for the RTTI system is explained first. Subsequently, the market volume and price elasticities of the digital product are determined. Once the required input variables have been set up in this way, the negotiation between the car manufacturer and the software suppliers is simulated and analyzed using the game theory model. Finally, the applicability of the developed model and its ability to balance the information asymmetry between purchasing and software suppliers are discussed.

#### 3.1 Assessing the Production Costs

The production costs  $c_1$  and  $c_2$  of both potential suppliers for the RTTI system are determined using the technology-oriented analogy method explained in Sect. 3. A satellite navigation device with DAB (Digital Audio Broadcasting) -TPEG (Transport Protocol Experts Group) service procured in 2015 is identified as a suitable reference product. The known monthly costs for this device are € 0.63 per individual license.

In the next step the technology maps that make up the satellite navigation reference device and the RTTI system are identified. The essential technological principles integrated into the products are focused on (see Table 2).

**Table 2** Technology types and technology attractiveness values

Satellite navigation device		RTTI system	
Technology type	Technology attractiveness	Technology type	Technology attractiveness
GPS	1	GPS	1
Map matching	1.5	Cloud platform	2
Digital maps	1.5	Data encryption	1
Digital compass	1	Big Data technologies	3
Routing methods	1.5	RFID	1.5
DAB	1	Artificial intelligence	3
TPEG	1.5	Sensor technology	1
Overall technological attractiveness	9	Overall technological attractiveness	12.5

The technology types of the satellite navigation device and the RTTI system are then evaluated based on technology attractiveness by expert groups and positioned on the S curve. The results of this investigation are summarized in Table 2. Figure 4 shows the ranking of the technologies on the S-curve. The more mature a technology is, the more data is available to describe its historical developmental lead (Eppinger et al. 2017). The corresponding technology attractiveness value is derived from the position of the technology type on the S-curve (see also Table 2).

Based on the overall technological attractiveness of the satellite navigation device and the RTTI system and the known production costs of the navigation device, the monthly target technology costs per individual license of the RTTI system are calculated according to formula 2:

$$c_{RTTI} = \frac{0.63\text{€}}{9} \times 12.5 = 0.88\text{€} \quad (9)$$

$c_{RTTI}$  monthly target technology costs per individual license of the RTTI system

PSM experts estimate that supplier 1 can offer the RTTI system at 69% lower costs per software license than supplier 2 because supplier 1 has a 69% higher market share. The unit costs of a digital product fall with increasing sales volume since variable costs tend towards zero and fixed costs are broken up according to the number of products sold. It is also assumed that supplier 2 produces the system at the previously estimated target costs per license. The estimated production costs of the suppliers are shown in Table 3.

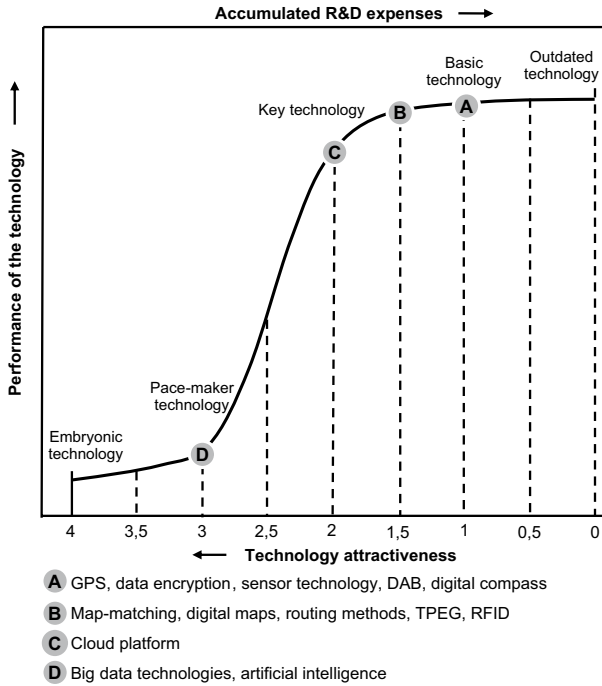


Fig. 4 Technology types on the S-curve

Table 3 Estimated production costs of suppliers for the RTTI system

	Production costs per license
Software supplier 1	$c_1 = 0.88 \text{ €} \times 31\% = 0.27 \text{ €}$
Software supplier 2	$c_2 = 0.88 \text{ €}$

### 3.2 Game Theory Based Analysis of Price Negotiations

In the following, the price negotiations between the car manufacturer and both software suppliers are analyzed. Table 4 shows the input parameters as an example.

The monthly production costs are borrowed from Sect. 3.1. The self and cross price elasticities of the RTTI system are estimated with the help of an experimental purchase simulation in the form of arc elasticities (see supplemental file (E)). The values determined in this way are finally validated in a group discussion in which in-house marketing experts participate. The market potential is also investigated by those experts, using market research data.

The car manufacturer acts as the leader of the Stackelberg game, the course of which can be illustrated by the game tree from Fig. 3 and is therefore the first to take the lead. The two software suppliers take on the role of followers and compete for the car manufacturer’s order to provide an RTTI system. It is assumed that all players behave rationally and strive to maximize their profits. Suppliers 1 and 2 produce RTTI systems 1 and 2 with identical product features and functionalities.

The systems differ only in the monthly production costs per license estimated in Sect. 3.1. All costs and prices are given and calculated monthly. The original equipment manufacturer (OEM) purchases the RTTI systems from suppliers 1 and 2 at wholesale prices  $w_1$  and  $w_2$ . The OEM then resells the RTTI services to customers at the retail prices  $p_1$  and  $p_2$ . All prices refer to the monthly use of a single license of the system.

In the first stage of the game, the car manufacturer decides on its negotiation strategy. The second stage of the game (see Fig. 3) involves the suppliers' decisions on revealing their production costs of the respective RTTI system. The strategy options of the players involved result in the scenarios listed in Table 1.

For each scenario, the benefits for the car manufacturer and the software suppliers are determined by their profit functions. These can be found in the supplemental file (B). The formulae for calculating the equilibrium wholesale and retail prices of the RTTI systems for all scenarios are derived from players' profit functions by backward induction and are in accordance with the formulae in the supplemental file (C, D). The input values from Table 4 are inserted into these formulae to calculate the average monthly equilibrium wholesale and retail prices of the RTTI systems listed in Table 5.

These prices are in turn used to calculate the profits for the relevant scenarios (for detailed formulae see supplemental file (B)). The average monthly profits calculated in this way are shown in Table 6. It must be noted that these values are the profits anticipated from the car manufacturer's point of view, based on its level of knowledge. The suppliers' profits are therefore calculated using the average production costs of the industry for those scenarios in which the car manufacturer does not know the actual production costs of a supplier (see Sect. 3.1).

**Table 4** Exemplary input variables

Monthly production costs per software license of supplier 1 $c_1$	0.27€
Monthly production costs per software license of supplier 2 $c_2$	0.88€
Average monthly market potential $\alpha$	2975
Self price elasticity $\beta$	$ -32.5  = 32.5$
Cross price elasticity $\gamma$	0.2

**Table 5** Balance prices per month per scenario

Scenario $x$	Wholesale price $w_{opt,x1}$ per month	Wholesale price $w_{opt,x2}$ per month	Retail price $p_{opt,x1}$ per month
1	23.43€		68.83€
2	23.31€		68.94€
3	23.31€		69.02€
4	23.43€		69.13€
5	23.13€	23.58€	68.98€
6	23.13€	23.36€	68.98€
7	23.36€	23.58€	69.06€
8	23.36€	23.36€	69.06€

**Table 6** Manufacturer and suppliers' profit per month per scenario

Scenario $x$	Profit of the car manufacturer $\pi_x^{AH}(p_{opt,x1}, p_{opt,x2})$ per month	Profit of supplier 1 $\pi_x^{L1}(w_{opt,x1})$ per month	Profit of supplier 2 $\pi_x^{L2}(w_{opt,x2})$ per month
1	67,456.55 €	17,321.62 €	16,422.96 €
2	67,697.35 €	17,148.63 €	16,698.58 €
3	67,578.65 €	16,862.87 €	16,416.61 €
4	67,462.43 €	16,869.30 €	16,869.30 €
5	67,677.25 €	16,984.48 €	16,746.83 €
6	67,898.62 €	16,868.78 €	16,869.83 €
7	67,564.29 €	16,865.24 €	16,866.24 €
8	67,669.09 €	16,869.15 €	16,869.15 €

### 3.3 Evaluation of the Results

The game theory based model provides a basis for the analysis of price negotiations by calculating equilibrium prices with the help of few input data, in this case market volume, price elasticities, and production costs. Without considering factors that would limit wholesale and retail prices, such as the maximum willingness to pay of customers and the car manufacturer, the profit-optimizing prices are very high. To improve the results in this respect, further assumptions and input variables must therefore be included in the model.

Due to the missing consideration of the car manufacturer's willingness to pay, the calculated equilibrium prices result in significantly higher profit margins for the suppliers than for the car manufacturer. In the scenarios examined here, the car manufacturer can only achieve a gross profit margin between 65.82 and 66.25%. For the software suppliers, the equilibrium prices of the cost model result in gross profit margins of between 96.22 and 98.85%. It is therefore questionable to what extent the cost model correctly reflects the profit margins of software suppliers.

The game theoretical cost analysis model in this basic version overestimates purchase prices for digital goods. With the help of the model, however, strategic recommendations for action can be derived for the car manufacturer by comparing all player's profits resulting from the equilibrium prices. Even if the absolute prices calculated by the model are very high, the comparison of the profit differences in the different scenarios can provide valuable information for the conduct of negotiations. This approach is explained below.

Figure 5 shows the monthly profits of the car manufacturer in the eight scenarios considered. The OEM makes the highest profit per month in scenario 6, which occurs if the car manufacturer applies a segmented negotiation strategy and only supplier 1 discloses its production costs. Scenario 1, on the other hand, is the scenario that shows the lowest profit per month for the car manufacturer. In this scenario, both suppliers decide to share their production cost information while the car manufacturer chooses to negotiate jointly.



The relationship between the car manufacturer’s respective profits per scenario (for a description of the scenarios see Table 1) can also be characterized as follows, starting from Fig. 5:

$$\pi_6^{AH}(p_{opt,61}, p_{opt,62}) > \pi_2^{AH}(p_{opt,21}, p_{opt,22}) > \pi_5^{AH}(p_{opt,51}, p_{opt,52}) > \pi_8^{AH}(p_{opt,81}, p_{opt,82}) > \pi_3^{AH}(p_{opt,31}, p_{opt,32}) > \pi_7^{AH}(p_{opt,71}, p_{opt,72}) > \pi_4^{AH}(p_{opt,41}, p_{opt,42}) > \pi_1^{AH}(p_{opt,11}, p_{opt,12}) \tag{10}$$

$\pi_x^{AH}$  Monthly profit of the car manufacturer in scenario  $x$ ,  $p_{opt,x1}, p_{opt,x2}$  equilibrium prices in scenario  $x$ .

Based on this formula, strategic recommendations for the OEM’s preparation for negotiations are derived below, depending on the behavior of the suppliers. If both software suppliers decide not to share their private information on the production costs of the RTTI system with the car manufacturer, the latter should negotiate individually and not jointly with the suppliers in order to maximize profit. The following applies ( $\pi_8^{AH}(p_{opt,81}, p_{opt,82}) > \pi_4^{AH}(p_{opt,41}, p_{opt,42})$ ). The same applies if both suppliers share their production cost information ( $\pi_5^{AH}(p_{opt,51}, p_{opt,52}) > \pi_1^{AH}(p_{opt,11}, p_{opt,12})$ ). A segmented negotiation policy is also the car manufacturer’s profit maximizing strategy if supplier 1, but not supplier 2, is willing to disclose information on its production costs ( $\pi_6^{AH}(p_{opt,61}, p_{opt,62}) > \pi_2^{AH}(p_{opt,21}, p_{opt,22})$ ). Joint negotiations with both software suppliers simultaneously only make sense for the car manufacturer if supplier 2 shares its production cost information with the RTTI system and supplier 1 does not ( $\pi_3^{AH}(p_{opt,31}, p_{opt,32}) > \pi_7^{AH}(p_{opt,71}, p_{opt,72})$ ).

Formula 10 also shows that the three scenarios in which the car manufacturer can make the greatest profits are combinations of strategies where supplier 1 decides to share its information on the production costs of the RTTI system. Consequently, it is sufficient for the car manufacturer to know the production costs of one software supplier to be able to negotiate profit-optimized wholesale and retail prices, insofar as this supplier is the one which can provide the RTTI system at lower production costs than the competing supplier. The car manufacturer’s optimal choice of strategy and the level of its profit is therefore determined mainly by its knowledge of the

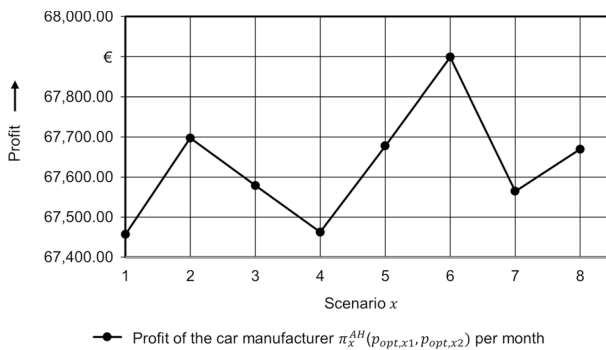


Fig. 5 Profit of the car manufacturer per month for all scenarios

suppliers' production costs in relation to the RTTI system and the behavior of the other players.

Figure 6 shows the monthly profits of the software suppliers for each scenario. A comparison of the monthly profits of supplier 1 for all scenarios shows the following relationship:

$$\pi_6^{L2}(w_{opt,62}) > \pi_4^{L2}(w_{opt,42}) > \pi_8^{L2}(w_{opt,82}) > \pi_7^{L2}(w_{opt,72}) > \pi_5^{L2}(w_{opt,52}) > \pi_2^{L2}(w_{opt,22}) > \pi_1^{L2}(w_{opt,12}) > \pi_3^{L2}(w_{opt,32}) \tag{11}$$

$\pi_x^{L2}$  Monthly profit of supplier 2 in scenario x

$w_{opt,x2}$  Equilibrium wholesale price for software supplier 2 in scenario x

This ranking shows that for supplier 2 the retention of its production cost information is always the optimal strategy to maximize its profits, regardless of the car manufacturer's negotiation policy and the information sharing strategy of supplier 1. The monthly production costs of supplier 2 are higher than the monthly production costs of supplier 1 and higher than the industry average production costs:

$$c_2 = 0.88 > \frac{c_1 + c_2}{2} = 0.58 > c_1 = 0.27 \tag{12}$$

$c_1$  Production costs of software supplier 1

$c_2$  Production costs of software supplier 2

The car manufacturer is keen to work with the more efficient supplier to achieve the lowest possible wholesale prices and correspondingly high profits. Consequently, it is not advantageous for supplier 2 to disclose the level of its production costs in any scenario. Even if supplier 1 does not disclose its production costs and the car manufacturer assumes that supplier 1 produces at the industry average production costs, these are still lower than the production costs of supplier 2.

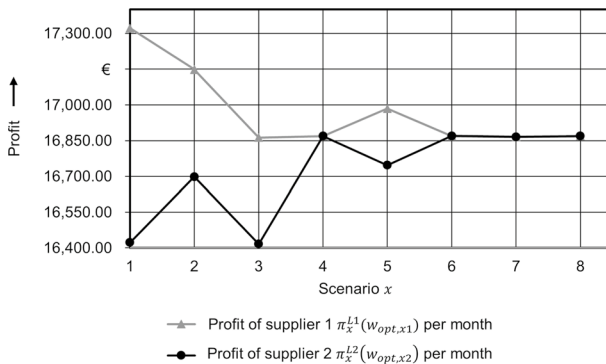


Fig. 6 Supplier profits per month for all scenarios

The analysis of the strategic options of the players, in particular the car manufacturer, using the cost model can be summarized as follows. Given the existing information asymmetry in the development or production costs of the RTTI system, the car manufacturer should negotiate prices with the suppliers individually, unless the less efficient supplier shares its production cost information, and the other does not. In this case, the car manufacturer achieves the highest possible profit through joint negotiations. In addition, to obtain the best possible profit, the OEM should encourage the more efficient supplier to cooperate and share its production cost information. This has a beneficial effect on the profits of both players. Information on the production costs of supplier 2, on the other hand, is of minor importance for the car manufacturer to generate maximum profits.

These results are built on the assumption that the car manufacturer does not know that the average costs of the industry are based only on the costs of the considered, two software suppliers. If this assumption is relaxed, scenarios 2,3, 6 and 7 can be neglected. The car manufacturer, knowing the costs of one supplier, can then calculate the production costs of the other supplier from the average costs. Consequently, only those scenarios in which the manufacturer knows the costs of both suppliers or has no information about the costs at all (scenarios 1,4,5 and 8) are still relevant in this context. However, this has almost no impact on the players' choice of the optimal strategy. As Fig. 5 shows, even neglecting scenarios 2,3,6 and 7, segmented bargaining represents the car manufacturer's profit-optimal strategy. Only the exception in the case that supplier 2 shares its cost information and supplier 1 does not, which arises in the examination of all scenarios, is eliminated in this consideration. The optimal strategy for the more efficient supplier (supplier 1) does not change at all, as Fig. 6 illustrates. This supplier is still in the best position if it shares the level of his production costs with the manufacturer. The same is true for supplier 2 if scenarios 2,3,6 and 7 are neglected. Its profit-optimal strategy also remains unchanged: it withholds its production cost information.

## 4 Conclusions

### 4.1 Summary of Results and Implications for Management

A game theory based cost analysis model in combination with a technology-oriented analogy method to support PSM is presented. PSM can derive strategic recommendations for negotiations with potential suppliers by comparing the equilibrium prices and the profits of the various scenarios that are influenced by the decisions of software suppliers regarding their strategy for passing on their production cost information. The case study results show that separate negotiations with suppliers are usually the better strategy for purchasing to deal with information asymmetries regarding production costs. The developed model includes the different levels of knowledge of PSM and suppliers regarding the production costs of digital goods. Although the developed game theory based model allows a qualitative comparison of the profit levels in different scenarios, it does not forecast concrete best practice prices for the product under consideration.

As a result of the megatrend of digital transformation purchasing is confronted with an increasing number of digital procurement objects, particularly software components. However, the information asymmetry between software providers and buyers regarding the development costs of these products (see Sect. 1) is a big challenge for the purchasing departments.

The game theory based model is an instrument to reduce the information advantage of software suppliers (see Sect. 1). Through a qualitative analysis of the profits in various scenarios, purchasing managers and supply managers can consider the optimal negotiation strategy and the positive effects that may result from passing suppliers' cost information. This transparency improves the basis for a partnership between suppliers and buyers (Bartlett et al. 2007).

In addition, the game theory based model is not only applicable for digital goods to be purchased but can also be used for the cost analysis of physical products. Consequently, the developed model represents a universal tool to support procurement tasks, which can be used independently of the company's industry and the product under consideration.

## 4.2 Limitations and Potentials

The developed negotiation model overestimates wholesale and retail prices. The reasons for this are, on the one hand, the efforts of the software suppliers and the purchasing department to generate the greatest possible profits, and, on the other hand, the lack of price limitations due to other influencing factors, such as the willingness of potential buyers to pay. The few input variables used and the assumptions of the game theory-based model simplify the context of the procurement of digital goods. For example, the model only includes the product attributes "price" and "costs" in the game theoretical analysis. It is obvious that the accuracy of the calculated equilibrium prices can be improved by considering additional input variables.

This can be done, for example, by extending the demand function (see supplemental file (A)) by a market sensitivity parameter with respect to the service level provided by the product, following the example of Deljavan and Sadeghi (Deljavan and Sadeghi 2012).

The service level of a digital product, such as the RTTI service, can be measured, for example, by the availability, response time or reliability of the system's data.

Such improvements would make it possible to better map the negotiations between the purchasing department and potential software suppliers and thus calculate more realistic equilibrium prices.

It must be noted, however, that extending the model to include additional input variables would increase in the already high data collection and data processing effort. Moreover, additional variables, such as the service level and the demand sensitivity of the market regarding the software component, would also increase the complexity of the model and thus the calculation effort. Purchasing and supply managers must weigh up to what extent an improvement in quantitative results of the model justifies this additional effort.

Furthermore, the model should be tested and validated against other procurement projects to ensure its generalizability. For this purpose, the results of the model can be compared with estimated software costs and prices, e.g., using traditional effort estimation methods from the software industry, such as COCOMO II, COSMIC or SLIM (Bodendorf et al. 2021c).

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## Declarations

**Competing interests** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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