University of Twente

Faculty of Behavioural, Management and Social Sciences

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Master Thesis

Topic: Mechanism design and how it could enhance the purchasing performance: Processes, success factors, selection criteria, and price developments

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AI	artificial intelligence
AMC	awareness-motivation-capability
BATNA	best alternative to a negotiated agreement
e.g.	exempli gratia
etc.	et cetera
n.a.	not applicable
OEM	original equipment manufacturer
RFQ	request for quotation
RQ	research question
R&D	research and development
t.b.d.	to be decided
VCG	Vickrey-Clarke-Groves

1 In quest of competitive advantage: The use of mechanism design theory to improve the purchasing performance

Bringing together interdisciplinary insights from economics, psychology, mathematics, computer science and other academic areas, game theory covers a diversified field of application that concerns strategic decision making. Common to all application areas is the awareness that most decisions made by individuals or organisations are not made in insolation but are influenced by the actions of other participants. Similarly, a solution to business problems is difficult to arrive at given conflicting interests and strategies of market actors. Game theory helps to model such decision situations and to identify courses of action that help individuals and organisations to achieve their individual preferences. Given game theory's systematic, quantitative approach for identifying optimal decision strategies, game-theoretic approaches received increased attention in recent years. The field of purchasing and supply management is no exception here.[1] For example, Zamarripa et al. (2013) developed a decision making tool based on game theory to find optimal production, inventory, and distribution profiles to provide a solution to the supply chain planning problem.[2] Likewise, Rigby et al. (2014) used game theory to explain why benchmarking through key performance indicators was not implementable in the UK construction sector.[3] Next to the academic interest, growing attention from practitioners can also be observed: a study about negotiations in difficult situations conducted by Drozak Consulting in collaboration with BME, the German association of materials management, purchasing and logistics, revealed that 37% of the surveyed procurement managers intend to deal more intensively with game-theoretic approaches in the future.[4]

Drawing on game-theoretic approaches, mechanism design theory could be particularly useful in improving the purchasing performance. The basic idea of mechanism design theory is to define the rules of an interaction game between market players in such a way that the mechanism designer achieves a desired outcome.[5] Therefore, mechanism design is often also referred to as market design.[6] For example, mechanism design theory can be used to analyse buyer-supplier interactions in which buyers – representing the mechanism designer – aim at incentivising their suppliers to

[1] See Harland et al. (2006), p. 745; Spina et al. (2013), p. 1209.
[2] See Zamarripa et al. (2013), p. 1596.
[3] See Rigby et al. (2014), p. 783.
[4] See Drozak Consulting (2014), p. 3.
[5] See Varian (2011), p. 365.
[6] See Varian (2011), p. 365.

share private information.[7] This information could concern, for instance, how attractive the award of a contract is for suppliers and might be used to motivate suppliers to optimise their cost structures.

The focus of this paper will be on mechanism design based negotiations. In this context, negotiations are regarded as strategic games, in which buyers and suppliers interact directly to determine optimal price levels from the buying organisation's perspective.[8] The main factor influencing the strategic behaviour of suppliers is their private information which is unknown to the buyer.[9] Therefore, buying organisations can rely on game theoretic approaches to design negotiations in such a way that suppliers are incentivised to reveal their plans to the buyer. This can be achieved based on the analysis of the participating suppliers, their objectives, and other given external parameters.[10]

Knowing the suppliers' private information, it is easier for buying organisations to achieve better purchasing prices. For instance, a buyer could use the knowledge on suppliers' true valuations of a contract in multi-unit auctions to design effective bundling strategies. Imagine a buyer intends to source two sets of similar products, termed packages, from the same set of five suppliers: one high-volume, very attractive and one low-volume, less attractive package. How can the buyer achieve the best result for both, the attractive and the unattractive package? One option could be the implementation of a qualification phase so that only those three suppliers that quoted the best prices for the low volume package are allowed to submit offers for the high volume package. By linking the attractive with the unattractive package, the suppliers' competitive pressure increases, thereby incentivising them to submit better quotes for both packages.[11]

Although research on mechanism design theory increased in the past and many buying organisations use this theory to design negotiations that aim at lowering purchasing prices, the topic still appears to be somewhat underrepresented in the 'traditional' purchasing and supply management literature. In particular, previous research focused on two different research directions. The first direction deals with specific questions, such as the allocation of public goods, the design of optimal auctions, and the structuring of contracts, while the second direction remains on a more tech-

[7] See McAfee & McMillan (1988), p. 338.
[8] See Kagel & Levin (2009), p. 1.
[9] See Wilson (1992), p. 230.
[10] See Klemperer (1999), p. 227; Chaturvedi et al. (2014), p. 1725.
[11] See Scheffler (2015), p. 83; Scheffler et al. (2016), p. 570.

nical level.[12] However, it remains unanswered how buying organisations can implement mechanism design based negotiations in practice. While several buying organisations already use mechanism design theory in negotiations, the academic literature appears to lack behind in providing guidance on how to do so. Therefore, the study at hand aims at answering the following four research questions:

RQ 1: *How does the process flow of mechanism design based negotiations differ from conventional approaches?*

RQ 2: *What are the success factors of mechanism design based negotiations compared to conventional approaches?*

RQ 3: *Which sourcing projects are suited for the application of mechanism design theory?*

RQ 4: *Which mechanisms can be designed by buying organisations and how does the interplay of various mechanisms influence purchasing prices?*

To close the gap between purchasing practice and supply management literature on mechanism design theory, the following sections provide a non-technical introduction to game theory as well as mechanism design theory and explore the benefits of applying the latter in the purchasing field. In addition, a case study was conducted at a large European automotive original equipment manufacturer (OEM) relying on thirteen semi-structured interviews, an extensive document review, and observations made during the researcher's full time stay at the case company. The results are used to develop detailed process flow descriptions that compare conventional and mechanism design based sourcing approaches. Furthermore, seven success factors are identified that highlight the peculiarities of this game theoretic negotiation method in order to identify how the efficacy of this newly introduced negotiation process is achieved. The analysis also revealed seven factors facilitating a successful project execution. These factors have been translated into a catalogue of criteria helping to identify the most promising sourcing projects for the application of mechanism design theory. By using this catalogue as a guideline, purchasing managers are argued to be able to allocate their scarce resources to those projects that are most likely to result in significant cost savings. Finally, three mechanisms have been identified that were applied most often in the OEM's negotiation designs to illustrate which mechanisms might be used by buying organisation to incentivise

[12] See Maskin (2008), p. 572.

suppliers to reveal their reservation prices. In addition, two sourcing projects have been taken as exemplary cases to describe how mechanisms can influence purchasing prices.

The study is structured as follows: Section 2 and Section 3 provide an extensive literature review on game theory and mechanism design theory. Subsequently, Section 4 presents an overview of the state of art in the purchasing related literature on mechanism design theory. Next, the methodology section explains the research approach and quality criteria applied. The research results are presented in Section 6 in order to answer the above-mentioned research questions. The study continues by providing a discussion of the application of mechanism design theory in the realm of purchasing and highlighting implications for theory and practice. Finally, limitations and further research direction are presented, followed by a conclusion.

2 Game theory

2.1 The foundations of game theory: Using mathematical models to study interacting decision makers

Almost every situation in our daily routine can be interpreted as a game. For instance, consider a scene from the movie “A Beautiful Mind”[13], a film based on the life of Dr. John Nash, a mathematician and Nobel Prize winner for economics. In this scene, Dr. Nash sits at a bar together with three friends when a stunningly beautiful blonde woman walks in, accompanied by four brunette friends. Nash’s friends joke who will win in successfully wooing the blonde, while Dr. Nash proposes to do the opposite: “If we all go for the blonde, we block each other and not a single one of us is going to get her. So then we go for her friends, but they will all give us the cold shoulder because nobody likes to be second choice. But what if no one goes to the blonde? We don’t get in each other’s way and we don’t insult the other girls. That’s the only way we win.”[14] Thus, Dr. Nash views the situation as a game and analyses how the men can achieve their goal of winning one of the women without getting in the way of their friends. This example illustrates the basis of game theory: small parts of reality are depicted as games and it is analysed how players within this game should act.[15]

[13] See Howard (2001).
[14] Howard (2001).
[15] See Osborne & Rubinstein (1994), p. 1.

Game theory "(…) can be defined as the study of mathematical models of conflict and cooperation between intelligent rational decision makers".[16] A game refers to any interaction between two or more players whose actions influence each other's decision processes.[17] These players represent, for example, individuals, firms, governments, and non-profit organisations.[18] Each player has certain personal preferences regarding the potential outcomes of the interaction game so that players are likely to act in a strategic way to influence the outcome to their own benefit.[19] A key assumption in game theory is that players are rational, which means that they act out of self-interest.[20] Since humans are limited in their computational and cognitive power[21], a player is considered to act rational if the actions help the player in reaching his objectives.[22] Accordingly, players prefer decisions that lead to the achievement of their personal preferences and thus maximise their own payoff,[23] for instance their profitability. To achieve a maximum payoff, the players follow an action plan, also termed interaction strategy,[24] helping the players to identify their optimal responses to the strategies chosen by all other players.[25] In other words, the players try to analyse their present situation, possible courses of action, as well as expectations and potential moves of their opposite players. This analysis helps to predict the future behaviour of their opponents. Ultimately, the players aim at responding to their opponents' courses of action in such a way that their own position is optimised.

Game theory is used to identify optimal outcomes of an interaction and to analyse which strategies should be pursued by the players in order to achieve it.[26] The solution concepts, also termed equilibria, predict the players' preferences and their strategic behaviour which ultimately result in the optimal outcome of the game.[27] Optimal outcomes can be based on two divergent objectives.[28] Either players intend to maximise their individual profit without being concerned about the other players' economic situation, or they aim at achieving an outcome that is Pareto-efficient. The latter

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16 Myerson (1991), p. 1.
17 See Myerson (1991), p. 2; Bicchieri (2004), p. 289; Lasaulce & Tembine (2011), p. 3.
18 See Manski (2000), p. 118.
19 See Luce & Raiffa (1989), p. 1; Jackson (2001), p. 655; Segal & Sobel (2007), p. 197.
20 See Myerson (1991), p. 1; Parsons & Wooldridge (2002), p. 243.
21 See Selten (1991), p. 4.
22 See Nida-Rümelin (1994), p. 3.
23 See Luce & Raiffa (1989), p. 5; Myerson (1991), p. 2; Baliga & Maskin (2003), p. 308.
24 See Dutta (1999), p. 20.
25 See Parsons & Wooldridge (2002), p. 243; McCain (2010), p. 5.
26 See Luce & Raiffa (1989), p. 6; Lasaulce & Tembine (2011), p. 4.
27 See Myerson (1991), p. 107; Jackson (2001), p. 657; Serrano (2012), p. 666.
28 See Maskin (2008), p. 568; Varian (2011), p. 351.

refers to an outcome where none of the players' situation can be improved without worsening the situation of another player. The extent to which an outcome is judged as optimal or desirable is context-dependent.[29] Both, Pareto-efficient and profit maximising outcomes, can be attained depending on the set of mechanisms used and the solution concept selected.[30] Let us consider the case of procurement auctions, also termed reverse auctions, meaning a buyer lets several suppliers compete against each other to drive down purchasing prices.[31] Here, the buyer can be assumed to prefer a revenue maximising outcome as opposed to a Pareto-efficient outcome. Due to its focus on analysing the interdependent dynamics between players' strategic moves, game theory is also known as interactive decision theory.[32]

An overview of key concepts delineated in this section can be found in Table 1.

Concept	**Definition**
Game	Any interaction between two or more players whose actions influence each other's decision processes (Myerson, 1991, p. 2; Bicchieri, 2004, p. 289; Lasaulce & Tembine, 2011, p. 3).
Player	The entities involved in a game that make strategic moves in order to maximise their own payoff (Luce & Raiffa, 1989, p. 5; Myerson, 1991, p. 2; Osborne & Rubinstein, 1994, p. 2; Baliga & Maskin, 2003, p. 308).
Action	A move in a game that helps a player in reaching his objectives (Nida-Rümelin, 1994, p. 3).
Payoff	A player's reward (positive or negative) resulting from an action (Shoham & Leyton-Brown, 2009, p. 144).
Strategy	A player's action plan that helps to identify optimal responses to the moves made by other players involved in the game (Dutta, 1999, p. 20; Parsons & Wooldridge, 2002, p. 243; McCain, 2010, p. 5).
Solution concept or equilibrium	Prediction about the players' expected actions resulting in the optimal outcome of the game (Myerson, 1991, p. 107; Jackson, 2001, p. 657; Serrano, 2012, p. 666)
Preferences	Each player has certain personal goals leading to favoured outcomes of the game (Luce & Raiffa, 1989, p. 1; Jackson, 2001, p. 655; Segal & Sobel, 2007, p. 197)

Table 1: Key concepts of game theory
Source: See references provided for each concept

[29] See Maskin (2008), p. 567.
[30] See Jackson (2001), p. 657.
[31] See Daly & Nath (2005), p. 158.
[32] See Myerson (1991), p. 1; McCain (2010), p. 5.

2.2 A taxonomy to provide an overview of the basic classification of games

To provide an overview of the basic classification of games, a taxonomy has been developed (see Figure 1). On the uppermost level, a key distinction in game theory is made between cooperative, non-cooperative, and biform games.[33]

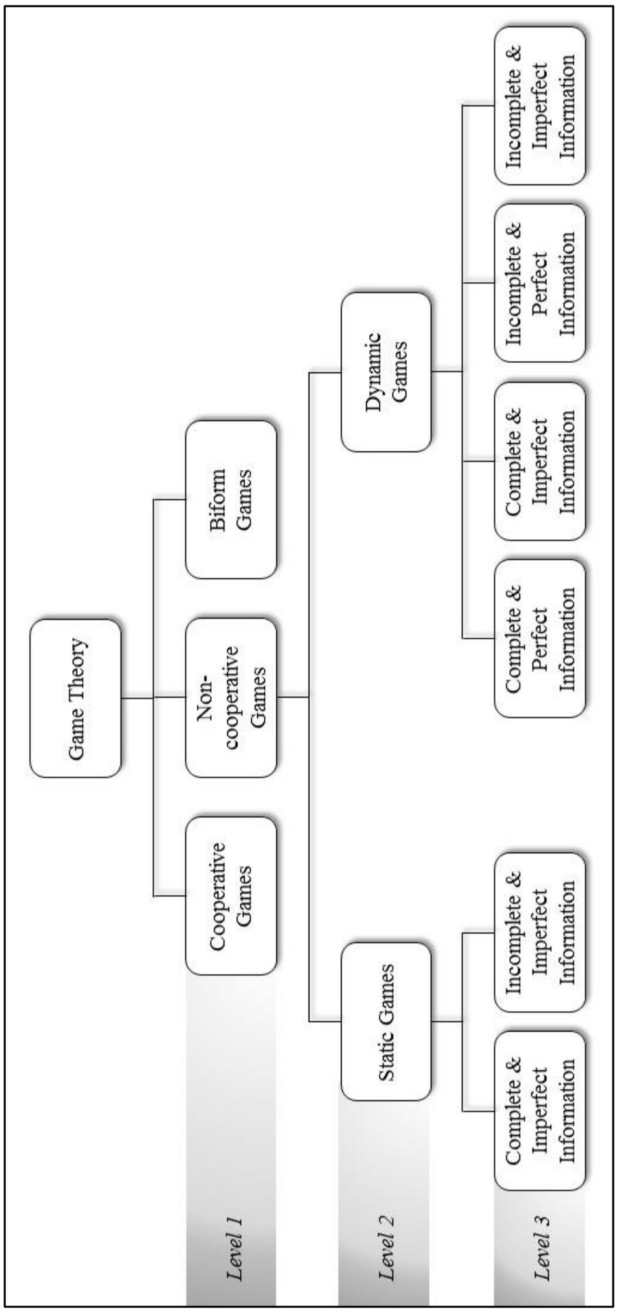

Figure 1: Taxonomy of games
Source: Own elaboration

[33] See Osborne & Rubinstein (1994), p. 2; Brandenburger & Stuart (2007), p. 537; Serrano (2012), p. 666.

Cooperative games refer to a game in which the players form a coalition and make binding commitments to coordinate their strategies in order achieve the best result for all entities participating in the game.[34] Here, the core question is: "What strategy choice will lead to the best outcome if we all choose a common, coordinated strategy?"[35] Simply put, players of cooperative games intend to achieve a win-win situation.[36] For instance, Zhao et al. (2010) show how a cooperative game theory approach can be applied to solve the problem of inefficient supply chains resulting from divergent objectives of buyers and suppliers: whereas retailers prefer to place short-term orders to deal with uncertain marked demand and avoid excessive inventory costs, manufacturers favour orders placed well in advance to guard against the risks of over- or underproduction.[37] This problem could be solved by the application of option contracts which consist of an option price, which means the retailer pays an allowance to the manufacturer for reserving production capacity, and an exercise price which is paid by the retailer for exercising his option when making use of the manufacturer's production capacity.[38] As a result, the manufacturer benefits from improved capacity planning due to the retailer's early commitment while the retailer can enjoy flexible order quantities.

Non-cooperative games depict situations in which players do not coordinate their strategies.[39] Instead, the players act autonomously whereby their decisions depend on their expectations about how their opponents are likely to act.[40] These expectations are made based on the players' knowledge of the rules of the games and the assumption that the players are acting rational, which means they take actions with the intent to maximise their own payoffs.[41] Here, the players' way of thinking surrounds the question: "What is the rational choice of a strategy when other players will try to choose their best response to my strategy?"[42] Moral hazard, referring to "self-interested unobservable behaviour",[43] lies at the heart of non-cooperative game theory.[44] For instance, buyers

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[34] See Shoham & Leyton-Brown (2009), p. 1; McCain (2010), pp. 403-404; Serrano (2012), p. 666.
[35] McCain (2010), p. 404.
[36] See Walley (2007), p. 16; Rusko (2011), p. 312.
[37] See Zhao et al. (2010), p. 668.
[38] See Zhao et al. (2010), p. 668.
[39] See McCain (2010), pp. 403-404.
[40] See Fudenberg & Tirole (1989), p. 261; Osborne & Rubinstein (1994), p. 255.
[41] See Fudenberg & Tirole (1989), p. 261.
[42] McCain (2010), p. 404.
[43] Mirrlees (1999), p. 4.
[44] See Kotowitz (1989), p. 210.

may encounter difficulties in monitoring and enforcing their suppliers' compliance with contractual agreements, potentially resulting in poor quality and delayed deliveries among others.[45]

While the distinction between cooperative and non-cooperative games has long been recognised in the literature on game theory, the notion of ***biform games*** has recently been developed by Brandenburger and Stuart (2007).[46] Biform games refer to a two-stage game, consisting of a non-cooperative game in the first stage and a cooperative game in the second stage.[47] In the first stage, the players' strategic actions are analysed, such as decisions about entering new supply markets, while the second stage identifies the amount of value captured by each player participating in the game.[48]

Since mechanism design theory, the core theme of this thesis, assumes that players engage in non-cooperative games,[49] this section does not further expand upon cooperative and biform games.

On a second level, games can be classified as static and dynamic games.[50] ***Static games*** (also termed strategic games) refer to single-stage games in which each player decides upon his strategy once and for all and the players implement their decisions simultaneously.[51] In this case, the players do not possess any knowledge about their opponents' strategic choices, which means that each player's strategy is chosen independent of the other player's action plans.[52] ***Dynamic games*** (also termed extensive games) are multi-stage games where players make their decisions sequentially.[53] Thus, all players are informed about the decisions taken by their opponents so before making the next move, they can change their strategies in response.[54]

Whereas mechanism design theory has initially been used in static game settings, recent research extended the applicability of mechanism design theory to involve dynamic games as well.[55] In both, static and dynamic games, a player's decisions are influenced by the information available about the other players. Therefore, various information settings are possible as depicted in Figure

45 See Williamson (1985), p. 29; Rindfleisch & Heide (1997), p. 47; Hoffmann et al. (2013), p. 200.
46 See Brandenburger & Stuart (2007), p. 538.
47 See Brandenburger & Stuart (2007), p. 538.
48 See Brandenburger & Stuart (2007), p. 538; Jia (2013), p. 1554.
49 See Narahari et al. (2009), p. 7.
50 See Osborne & Rubinstein (1994), p. 3.
51 See Cachon & Netessine (2004), p. 3; Narahari et al. (2009), p. 14; Narahari (2014), p. 26.
52 See Osborne & Rubinstein (1994), p. 3; Cachon & Netessine (2004), p. 3.
53 See Osborne & Rubinstein (1994), p. 87; Narahari (2014), p. 26.
54 See Roberts (1989), p. 238; Osborne & Rubinstein (1994), p. 3; Cachon & Netessine (2004), p. 3.
55 See Edelman & Schwarz (2010), p. 597; Athey & Segal (2013), p. 2464; Pavan et al. (2014), p. 601.

1.[56] To be more precise, the third level specifies several combinations of perfect and imperfect as well as complete and incomplete information settings for static and dynamic games.

Perfect information games describe situations in which all players have full knowledge of their own past moves as well as the past actions of all other players involved in the game before deciding on a move. For instance, chess games represent settings with perfect information.[57] Before deciding on the next move, both players are fully informed about their opponent's past decisions. If players do not know the entire history of past actions, for instance because actions are made simultaneously, the game depicts an ***imperfect information setting***.[58] Poker is an example of a setting with imperfect information.[59] Here, a player does not have full knowledge of an opponent's past decisions since strategies like bluffing may conceal the true strategic choices.

However, having full knowledge of the opponents' past moves does now imply that the players are informed about each other's plans and motivations. Such information is shared in ***complete information games***, which imply that each player is aware of all other participants in the game and is able to observe the other's strategies, preferences and payoffs.[60] In contrast, in a setting of ***incomplete information***, the players are only able to observe their own strategies and payoffs, which means that knowledge about each player's strategies is private information which is not made public to other opponents.[61] In this case, players can determine their optimal strategies without considering the other players' strategies. For example, incomplete information settings may arise when suppliers claim to be able to fulfil a buyer's production specifications; however, the buyer is not able to verify the supplier's manufacturing capabilities before rewarding a contract.

2.3 Identification of equilibria: The interdependence between information environments and solution concepts

The interactive nature of game theory highlights that the outcome of a game ultimately depends on the decisions made by all players participating in the game.[62] The appropriate solution concepts

[56] See Roy et al. (2010), pp. 4, 6.
[57] See McDonald (2007), p. 698; McCain (2010), p. 10.
[58] See McCain (2010), p. 11; Narahari (2014), p. 27.
[59] See McDonald (2007), p. 698; McCain (2010), p. 11.
[60] See Bicchieri (2004), p. 290; Kim (2014), p. 27.
[61] See D'Aspremont & Gérard-Varet (1979), p. 27; Baliga & Maskin (2003), p. 311; Narahari (2014), p. 27.
[62] See Bicchieri (2004), p. 289.

leading to optimal outcomes, also termed equilibria, differ depending on the information environment of the interaction game.[63]

In non-cooperative, static games with complete information, Nash equilibria are implemented.[64] In this information environment, each player is able to correctly predict the behaviour of the other players. Hence, each player's strategy is optimal given the strategic choices of all other players so that none of the players has an incentive to deviate from his chosen strategy.[65] Put in other words, Player 1 and Player 2 are in Nash equilibrium if both players make the best decisions they can, taking into account their opponent's decision provided that none of the players decides to change his strategy unexpectedly.

If the environment is characterised by an incomplete information setting, the players can determine their optimal strategies without considering the other players' strategies. Accordingly, optimal outcomes have initially been defined in terms of dominant strategies which lead to the highest expected payoff irrespective of the other players' behaviour.[66] In other words, a dominant strategy equilibrium implies that all players' chosen strategies are always best no matter how the other participants of a game decide to act. However, the strong assumptions of dominant strategies are difficult to satisfy, which means that implementable equilibrium outcomes are rarely identified.[67]

The development of the Bayesian implementation model represents a solution to the complicated identification of outcomes under incomplete information.[68] A Bayesian Nash equilibrium is a Nash equilibrium in the setting of incomplete information.[69] Here, uncertainty about the other players' strategies and payoffs is transformed from an incomplete information problem to an imperfect information problem so that the players choose strategies that maximise their expected payoffs based on their predictions about the other players' strategies and payoffs.[70] Hence, a Bayesian implementation only requires that each player is willing to use his equilibrium strategy when expecting that the other players will do so as well, whereas dominant strategy equilibria as-

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[63] See Baliga & Maskin (2003), p. 311.
[64] See Osborne & Rubinstein (1994), p. 14; Marinatto & Weber (2000), p. 293; McCain (2010), p. 75.
[65] See Varian (2011), p. 581.
[66] See Baliga & Maskin (2003), p. 316.
[67] See Hehenkamp (2007), p. 769; Varian (2011), p. 580; Blume et al. (2015), p. 5.
[68] See Rosenthal (1978), p. 595; Dasgupta et al. (1979), p. 206; Harris & Townsend (1981), p. 34.
[69] See Harsanyi (1967-8), p. 175.
[70] See Harsanyi (1967-8), p. 175; Reniers & Pavlova (2013), p. 53.

sume that players pursue their equilibrium strategy irrespective of what the other players do, thereby complicating the identification of optimal outcomes.[71]

Real-life interactions typically consist of environments with incomplete information. The following section about the 'Prisoner's Dilemma' presents an application example of a game with an incomplete information environment and a dominant strategy equilibrium.[72]

2.4 Application example: The Prisoner's Dilemma

The most prominent example of a game analysed in game theory constitutes the so-called 'Prisoner's Dilemma'. Varian (2011) explains the Prisoner's Dilemma as follows:[73] Two individuals committed a crime. Both are interrogated in two separate rooms without any possibility to communicate with each other. Each criminal has two options: confessing to the crime and thereby implicating the other, or denying to having participated in the crime. The prosecutors offer both criminals the following:

- If both players confess, each will serve three months in prison.
- If both players lie, each will serve one month in prison.
- If only Player A confesses while Player B lies, Player A will be set free and Player B will serve six months in prison (and vice versa).

An overview of the players' payoffs is depicted in Figure 2. Putting ourselves in Player A's position, it is always best to confess: if Player B decides to lie, Player A will be set free, and if Player B decides to confess, Player A will serve three months instead of six months which Player A would have to serve when lying. The same applies to Player B: irrespective of the decision taken by Player A, Player B is always better off when confessing to the crime.

In sum, if both players act rational to optimise their own payoff, confessing would be the best strategy for both players independent of the other player's behaviour. Confessing thus represents a dominant strategy for both players.[74] However, acting rational prevents the players from a Pareto-efficient outcome which would be achieved if both players lied: in this case, both would only serve

[71] See Baliga & Maskin (2003), p. 320; Varian (2011), p. 580.
[72] See Kreps et al. (1982), p. 246; Andreoni & Miller (1993), pp. 570, 573; Deng & Deng (2015), p. 2.
[73] See Varian (2011), pp. 584-585.
[74] See McCain (2010), p. 54.

one month. Here, none of the players' detention period can be shortened without prolonging the detention period of another player. Yet, this outcome can only be attained if both players could coordinate their decisions, for example through communicating with other. Because of the separate rooms, this is not possible in the Prisoner's Dilemma.

		Player B	
		Confess	*Lie*
Player A	*Confess*	-3, -3	0, -6
	Lie	-6, 0	-1, -1

Figure 2: Prisoner's Dilemma
Source: Based on Varian (2011), p. 585

The key message of the Prisoner's Dilemma is that the highest payoff for all players can be achieved if they are informed about the other players' strategies. This can be achieved through incentivising the players to share information. Mechanism design theory centres around exactly this idea and will be explained in further detail in the following section.

3 Mechanism design theory

3.1 The foundations of mechanism design theory: Prescribing the rules of the game to implement desired outcomes

In terms of the taxonomy of games provided in Figure 1, mechanism design theory assumes that players engage in non-cooperative games with incomplete information.[75] While mechanism design theory uses game theory as a tool to identify and analyse the rules of the interaction game,[76] it still differs from game theory in some important respects. Game theory focusses on decision situations in which the rules of the game and the players' preferences for certain outcomes of the game are

[75] See Narahari et al. (2009), p. 7.
[76] See Roth (2002), p. 1342; Dash et al. (2003), p. 40.

considered as given.[77] Thus, game theory poses the question of how the players are likely to act given the rules of the game, identifies potential outcomes of the interaction game, and analyses the outcomes' attributes, such as Pareto-efficiency.[78] In contrast, mechanism design theory represents the inverse of game theory and asks instead: What is the desired outcome and how can the rules of the game be designed to achieve this outcome?[79] Thus, by taking an engineering perspective, the mechanism designer is in a position to prescribe the rules of the game.[80] Referring back to the Prisoner's Dilemma introduced in Section 2.4, the legal system is designed in such a way that both criminals have an incentive to confess. This logic to incentivise a player to act in a desired way could also be used in purchasing and supply management. One field of application could be procurement auctions. For instance, buying organisation may attempt to design optimal auctions that maximise competition between suppliers by applying elements such as information feedbacks and rankings so that purchasing prices are driven down.[81] In sum, both game theory and mechanism design theory can be considered as branches of the same tree: game theory takes interaction games as given and then analyses the outcome while mechanism design theory is used to design the interaction game in order to achieve a desired outcome.[82] The relation between game theory and mechanism design theory is also depicted in Figure 3.

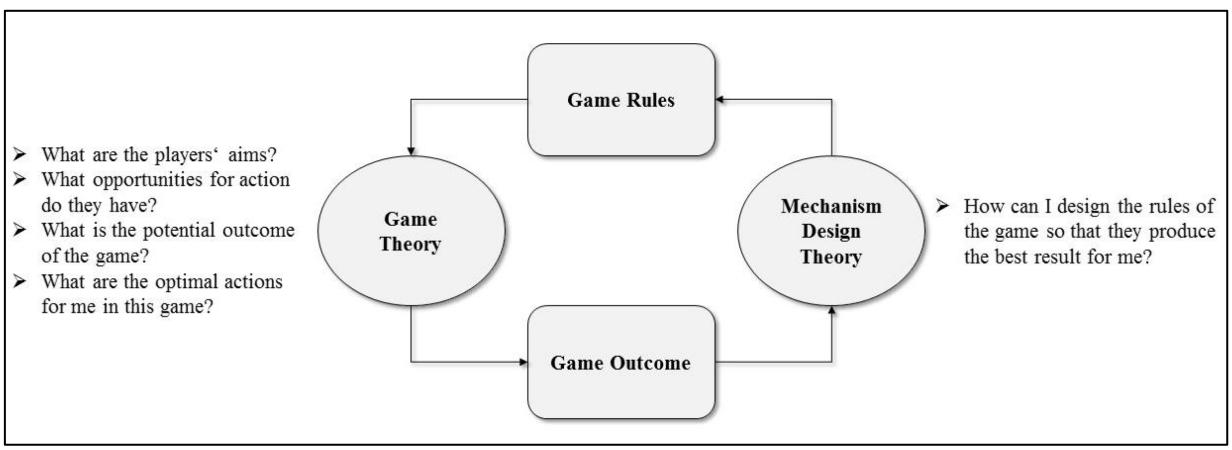

Figure 3: Relation between game theory and mechanism design theory
Source: Based on Moura et al. (2014), p. 100 & own elaboration

[77] See Varian (2011), p. 365.
[78] See Hehenkamp (2007), p. 769; Maskin (2008), p. 567; Moura et al. (2014), p. 100.
[79] See Hehenkamp (2007), p. 769; Maskin (2008), p. 567; Han et al. (2012), p. 226.
[80] See Nisan (2007), p. 209.
[81] See Scheffler (2015), p. 83; Scheffler et al. (2016), p. 570.
[82] See Jackson (2001), p. 656.

Mechanism design theory in negotiations can be regarded as an extension of purchasers' traditional toolbox of sourcing tactics. In the past, operations management research has analysed alternative sourcing approaches.[83] These include cost-oriented tactics, such as pooling of demand, price evaluation, and global sourcing, as well as innovation-oriented tactics, such as product optimisation, process optimisation, supplier integration, and commodity-spanning tactics, the latter concern trade-offs in cost reductions between different materials and services.[84] Mechanism design theory can be regarded as a price evaluation tactic which refers to the use of enhanced negotiation techniques, including game theoretic negotiation designs and auctions.[85] Figure 4 shows the basic decomposition of profit and illustrates how mechanism design theory can act as an 'adjusting screw' to bring leverage to bear on the price component of profit. In particular, profit represents the difference between an organisation's revenue and costs. Costs are comprised of variable and fixed costs while revenue is the result of the quantity of products sold multiplied by the sales price.[86] Purchasers can use mechanism design to alter the price component of an organisation's products and services by optimising the input prices so that the price structure is changed.

[83] See Horn et al. (2013), p. 34.
[84] See Sakurai (1990), p. 251; Trent (1998), p. 52; Arnold (1999), p. 167; Wagner et al. (2002), p. 262; Schumacher et al. (2008), p. 36; Schiele et al. (2011), pp. 322-323.
[85] See Schiele et al. (2011), p. 322.
[86] See Menden & Seyfferth (2014), p. 39.

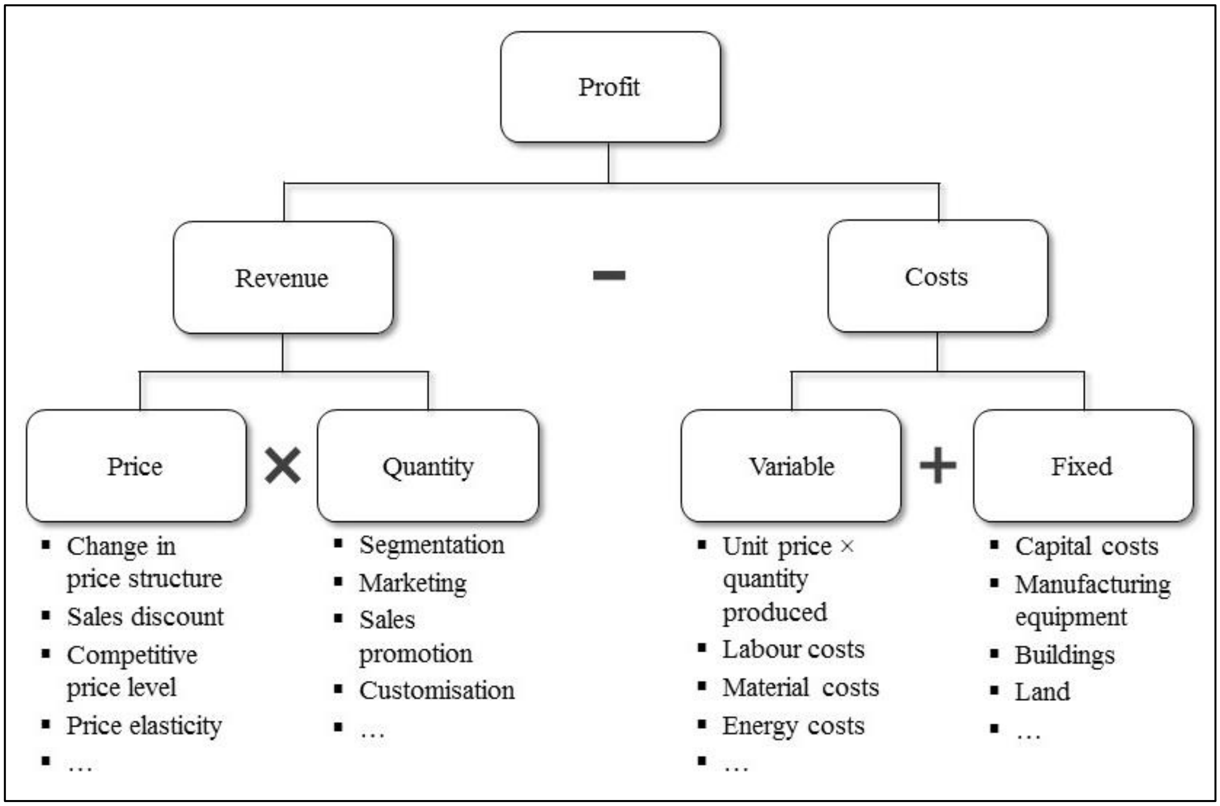

Figure 4: Basic decomposition of profit
Source: Based on Menden & Seyfferth (2014), p. 39

The foundations of mechanism design theory were laid by the seminal work of Hurwicz (1960).[87] He defined a mechanism as a communication game in which players exchange messages that collectively specify the outcome of the game.[88] These messages can be understood as actions taken by the players resulting from their interaction strategies and may comprise private information (such as the players' preferences), be of varying truthfulness and completeness (since players may withhold information that could harm them), and occur sequentially or simultaneously.[89] The mechanism acts like a machine that takes as input all received messages and processes them based on the assumption that each player aims at maximising his own payoff.[90] As a result, this information processing leads to the prescription of rules for the interaction game which assign an out-

[87] See Hurwicz (1960), p. 27.
[88] See Hurwicz (1960), p. 31.
[89] See Hehenkamp (2007), p. 769.
[90] See McAfee & McMillan (1988), p. 337; Hehenkamp (2007), p. 796.

come (e.g. an allocation of products and services) to every combination of received messages.[91] In other words, a mechanism refers to the rules of the interaction game which specify a set of possible actions for each player and an outcome as a function of these actions.[92] The specific design of the interaction game, such as negotiation rules, impacts the players' strategic behaviour and the ultimate outcome of the game.[93] Changing the mechanism leads to different games, resulting in alternative outcomes.[94] A key difficulty in mechanism design theory is that the mechanism designer normally does not have complete information about how the participants of a game are likely to act because it may not be in the players' best interest to report their preferences.[95] Without knowledge on the players' preferences, mechanism designers cannot identify which outcomes are optimal in advance.[96] For example, when designing procurement auctions, buyers generally do not know how much potential suppliers value being awarded with the contract. Therefore, it is necessary to incentivise the suppliers to share this private information. This is known as incentive compatibility and explained in the following section.

3.2 Key concepts in mechanism design theory: Individual rationality, incentive compatibility, and the revelation principle

Central to the advancement of mechanism design theory are the concepts of individual rationality, incentive compatibility, and the revelation principle. The approach followed to identify an optimal outcome of an interaction game starts with identifying the set of feasible mechanisms, and then determining the equilibrium concept used to predict the players' actions in the game.[97] Both, individual rationality and incentive compatibility represent key constraints in identifying optimal outcomes.[98]

Mechanism design theory assumes ***individual rationality***, which means the players participate in the mechanism out of free will.[99] Individual rationality adds a participation constraint, stating that

[91] See Hurwicz (1960), p. 31; McAfee & McMillan (1988), p. 337; Hehenkamp (2007), p. 769.
[92] See Jackson (2001), p. 656.
[93] See Jackson (2001), p. 656.
[94] See Myerson (2008), p. 587.
[95] See Jackson (2001), p. 656.
[96] See Maskin (2008), p. 568.
[97] See Prize Committee of the Royal Swedish Academy of Sciences (2007), p. 4; Serrano (2012), p. 666.
[98] See McAfee & McMillan (1988), p. 336.
[99] See McAfee & McMillan (1988), p. 336; Nisan (2007), p. 209.

the expected payoff of any player is not worsened through partaking in the mechanism.[100] Put differently, the mechanism designer – here the buyer – has to ensure that the negotiation is designed in such a way that the suppliers are at least as well off as they would have been if they had not participated in the negotiation.

To explain ***incentive-compatibility***, we assume that the mechanism designer applies a direct mechanism, which means a mechanism that provides each player with an incentive to reveal his private information.[101] However, a direct mechanism does not imply that the players tell the truth, so that relevant private information may not be communicated resulting in sub-optimal outcomes of the interaction game.[102] The players will only be truthful if they have a personal interest in being honest. A mechanism is said to be incentive-compatible if an equilibrium exists in dominant strategies that results in a maximum payoff for all players when reporting their private information truthfully.[103] Incentive-compatible mechanisms help mechanism designers in gathering information about the players' individual preferences, such as suppliers' true valuations of being awarded with a contract, thereby making it easier to identify in advance which outcomes are optimal.

Incentive compatibility solves both issues of adverse selection and moral hazard. Referring to a buyer-supplier relationship, adverse selection refers to a situation of asymmetric information in which a supplier has information or knowledge, for instance about the quality of his products, that is unknown to the buyer.[104] Asymmetric information can result in market failure as illustrated by Akerlof's (1970) popular model of the used car market, which is also called the 'Lemons Problem':[105] A buyer wants to purchase a used car; yet, he has not enough knowledge to ascertain the true value of the vehicles presented to him. Therefore, the buyer is only willing to pay an average price. While this price is favourable for sellers of defective cars, known as lemons, sellers of used cars with good quality make a loss since their cars would be worth more if the buyer had accurate knowledge of the vehicles' true value. In the end, sellers of good used cars are driven out of the market due to their inability to make sufficient profit, leaving only lemons behind.[106] A similar

[100] See McAfee & McMillan (1988), p. 343; Hehenkamp (2007), p. 769.
[101] See McAfee & McMillan (1988), p. 338.
[102] See Hehenkamp (2007), p. 769.
[103] See Hurwicz (1972), p. 300; McAfee & McMillan (1988), p. 338; Nisan (2007), p. 218.
[104] See Balakrishnan & Koza (1993), p. 100; Thomsen & Conyon (2012), p. 21; Gailmard (2014), p. 92.
[105] See Akerlof (1970), p. 489; Leland (1979), p. 1329; Wilson (1979), p. 313.
[106] See Akerlof (1970), p. 489.

situation could occur in supply markets if buyers have incomplete knowledge about the quality of their suppliers' products, so that buyers are only willing to pay an average price, making high-quality suppliers leaving the market. Moral hazard implies that the buyer has imperfect information about the supplier's privately taken actions, which therefore cannot be contracted upon so that a buyer may select suppliers which do not apply enough effort in using their skills and capabilities.[107] For example, buyers could design contracts that lock-in supplier in a long-term relationship by requiring the supplier to make relationship-specific investment, such as investments in tooling and equipment. If the potential loss of these investments in case of an early contract annulation on behalf of the buyer exceeds the profits to be gained from an on-going relationship with the buyer, the supplier has a strong disincentive to act opportunistically[108]. Put differently, suppliers who know that their product quality does not meet the buyer's expectations (adverse selection) and/or who are not willing to show sufficient effort to satisfy the buyer's demands (moral hazard) are unlikely to agree on a contract that includes significant relationship-specific investments. Thus, incentive-compatible mechanisms help buying organisations by incentivising players to share their private information honestly and motivating them to act obediently.[109]

Next to the range of direct mechanisms which provide each player with an incentive to reveal his private information, the design of many other random, more natural, mechanisms is possible to solve complex situations.[110] Compared to random mechanisms, the class of direct mechanisms is considerably smaller; additionally, they are easier to identify and analyse due to their mathematical characteristics.[111] However, since direct mechanisms are the simplest type of mechanisms which ask players in a straightforward way to reveal private information, direct mechanisms have little practical application.[112]

Given this great menu of possible direct and random mechanisms, how can we be sure that we have found the best mechanism available? A major advancement of mechanism design theory, providing an answer to this question, was the scientific discovery of *the* ***revelation principle***, in-

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[107] See Pauly (1974), p. 45; Hölmstrom (1979), p. 74; Stump & Heide (1996), p. 432; Thomsen & Conyon (2012), p. 21.
[108] See Stump & Heide (1996), p. 432.
[109] See Myerson (2008), p. 588.
[110] See McAfee & McMillan (1988), p. 338; Palfrey (2002), p. 2274.
[111] See Myerson (2008), p. 588.
[112] See Nisan & Ronen (2001), p. 172; Palfrey (2002), p. 2274; Myerson (2008), p. 588; Narahari et al. (2009), p. 9.

troduced by Gibbard (1973).[113] The revelation principle states that every random mechanism can be reproduced by an incentive-compatible direct mechanism that leads to the same equilibrium outcome.[114] In other words, when identifying optimal outcomes, attention can – despite the large amount of possible random mechanisms – be restricted to the comparatively smaller set of direct mechanisms.[115] Therefore, the revelation principle reduces the identification of optimal mechanisms to a well-defined mathematical task while direct mechanisms can eventually be transformed back to more realistic ones.[116] Myerson (1979, 1982, 1986) developed the revelation principle in its most general version, which not only applies when players have private information but also in the case of moral hazard and mechanisms having multiple stages.[117]

Subsequent research has addressed two main issues, namely the implementation problem and the design problem.[118] Concerning the former, both, incentive compatibility and the revelation principle, do not guarantee that only one equilibrium exists: accordingly, the implementation problem concerns the possibility of having multiple equilibria, some of which are sub-optimal.[119] The solution to this problem, developed by Maskin (1977), is known as implementation theory and constitutes a central part of modern mechanism design theory (see Figure 5).[120] He showed that equilibria are Nash implementable when the necessary condition of Maskin monotonicity and the sufficient condition of having at least three players without any veto power are fulfilled.[121] Maskin monotonicity implies that for all players an initially selected course of action remains optimal even if the players' preferences change.[122] In addition, there must be at least three players participating in the game, none of which has any veto power which means that if all but one of the players agree that a certain outcome is regarded as optimal, the remaining player cannot prevent this outcome by

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[113] See Gibbard (1973), p. 599.

[114] See McAfee & McMillan (1988), p. 335; Epstein & Peters (1999), p. 119; Myerson (2008), p. 588.

[115] See Myerson & Satterthwaite (1983), p. 267; Nisan (2007), p. 224.

[116] See McAfee & McMillan (1988), p. 336; Prize Committee of the Royal Swedish Academy of Sciences (2007), p. 3; Narahari et al. (2009), p. 9.

[117] See Myerson (1979), p. 61; Myerson (1982), p. 67; Myerson (1986), p. 323; Prize Committee of the Royal Swedish Academy of Sciences (2007), p. 5.

[118] See Blume et al. (2015), p. 2.

[119] See Jackson (2001), p. 660; Hehenkamp (2007), p. 771.

[120] See Maskin (1977), p. 24; Prize Committee of the Royal Swedish Academy of Sciences (2007), p. 14.

[121] See Maskin (1977), p. 24; Williams (1986), p. 146; Repullo (1987), p. 39; Saijo (1988), p. 694; Jackson (2001), pp. 665, 668.

[122] See Hehenkamp (2007), p. 772; Maskin (2008), p. 572.

trying to veto it.[123] While Maskin (1977) only focused on games with complete information, implementation theory has been extended to include games with incomplete information as well.[124]

The design problem deals with practical questions asking how mechanism design theory can inform decisions on regulation, taxation, insurance design, the provision and financing of public goods, revenue management, and non-linear pricing among others.[125] A central topic in the field of purchasing and supply management represents the use of mechanisms to design optimal auctions.[126] The following section provides an example of an incentive-compatible mechanism used in auction design.

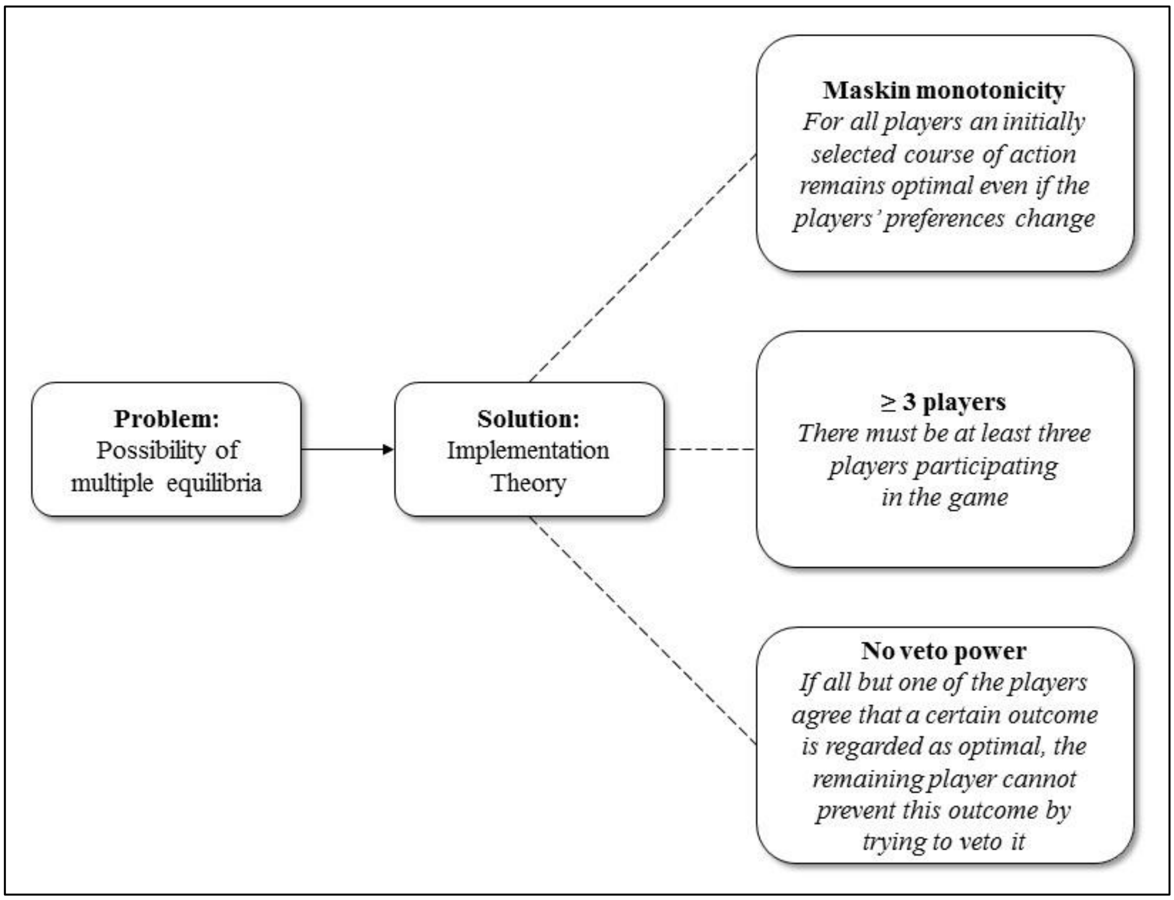

Figure 5: Overview implementation theory
Source: Own elaboration

[123] See Hehenkamp (2007), p. 772; Maskin (2008), p. 574.
[124] See Postlewaite & Schmeidler (1986), p. 662; Palfrey & Srivastava (1989), p. 116; Mookherjee & Reichelstein (1990), p. 455; Jackson (1991), p. 464; Jackson (2001), p. 678.
[125] See Baliga & Maskin (2003), p. 308; Hehenkamp (2007), p. 771; Bergemann & Pavan (2015), p. 679; Blume et al. (2015), p. 2.
[126] See Myerson (1981), p. 58; Chaturvedi et al. (2014), p. 1725; Skreta (2015), p. 855.

3.3 Application example: The Vickrey-Clarke-Groves mechanism

The application of mechanism design theory will be illustrated using the example of Vickrey-Clarke-Groves (VCG) mechanisms which are often applied in auction design. The following illustration refers to a procurement auction.

VCG mechanisms denote a class of incentive-compatible, direct revelation mechanisms[127] so that the truthful communication of private information represents a dominant strategy for all suppliers. In other words, suppliers reveal their plans to the buyer. Rieck et al. (2015) explain the rules of VCG mechanisms as follows:[128] each supplier participating in the auction independently submits a single offer without any knowledge about the prices offered by his competitors. The auction ends at a predetermined point in time and the buyer awards the supplier who submitted the lowest offer. However, the best supplier receives the purchasing price asked by the second best supplier. Therefore, VCG auctions are also referred to as sealed-bid second-price auctions. When VCG mechanisms are applied, it is always optimal for suppliers to offer their reservation price, which means the price point at which a seller is indifferent between winning or ending the negotiation, that is the lowest selling price a supplier is willing to accept before walking away.[129]

A simple numerical example should further clarify the functioning of VCG mechanisms. We assume that there are two suppliers participating in an auction. Supplier A has a reservation price of €50. However, Supplier A tries to achieve a higher price for his goods by making a strategic offer of €60. In the first scenario, Supplier B offers €65. Thus, Supplier A offered the best price and will receive €65 irrespective of whether Supplier A asked for €50 or €60 (see Scenario 1 in Figure 6). In the second scenario, Supplier B offers €40, so Supplier A will not be awarded (see Scenario 2 in Figure 6). In this case again, it would not make any difference whether Supplier A asked for €50 or €60. However, in the last scenario, Supplier B offers €55 which lies between Supplier A's reservation price of €50 and his strategic offer of €60. Now, Supplier A will not be awarded although his true reservation price was lower than the best offer made by his competitor (see Scenario 3 in Figure 6). This simple scenario highlights that it is never pays off for suppliers to influence the purchasing price through strategic offers. Instead, the dominant strategy for each supplier is always

[127] See Bergemann & Välimäki (2010), p. 787; Zhang et al. (2012), p. 391.
[128] See Rieck et al. (2015), pp. 30-31.
[129] See Van Poucke & Buelens (2002), p. 68.

to ask for his lowest selling price because the second best price will be rewarded in the end and the supplier thereby achieves an on-top income on his reservation price.

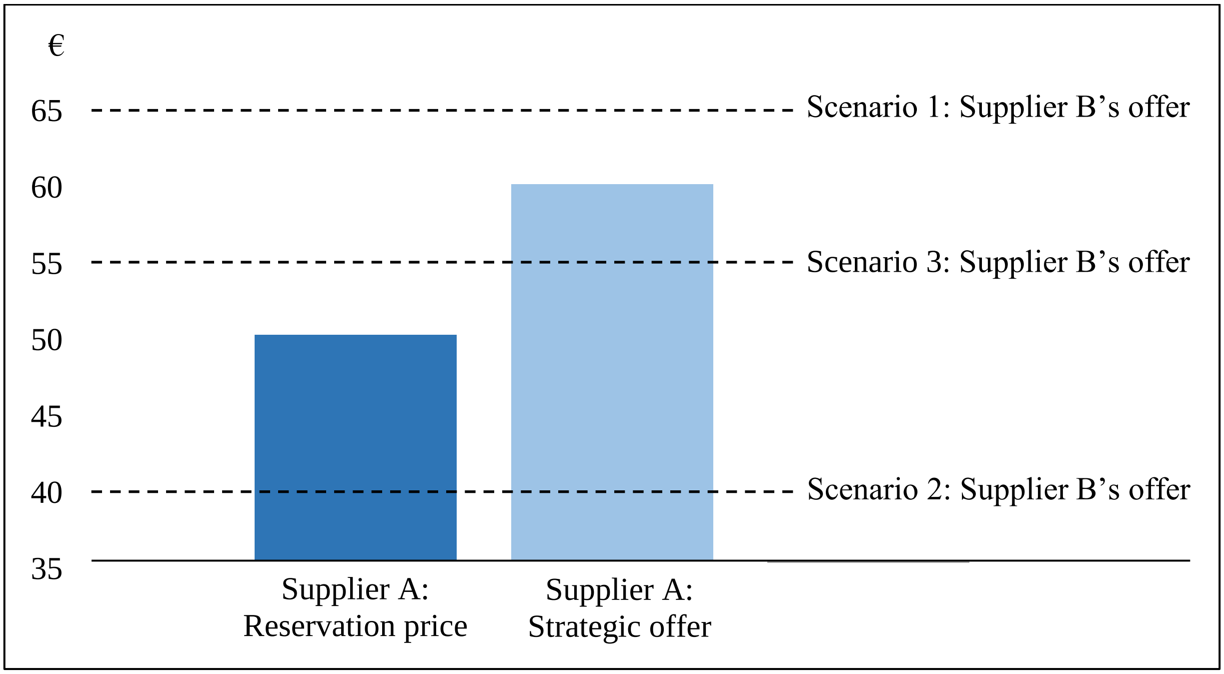

Figure 6: Scenarios for VCG mechanisms
Source: Own elaboration

4 The application of mechanism design theory in negotiation design

Negotiations can be regarded as strategic games in which buyers and suppliers interact directly to determine optimal price levels.[130] The main factor influencing the strategic behaviour of bidders is their private information.[131] Therefore, decisions on negotiation designs are often based on game-theoretic approaches whereby optimal outcomes are derived from the analysis of the participating players, their objectives, and given external parameters.[132] Based on this information, it is possible to design negotiations in such a way that the final outcome can be influenced in the desired direction.

VCG mechanisms, introduced in the previous section, highlight that the best strategy for suppliers is to bid their reservation prices. Nevertheless, previous research has shown that suppliers often

[130] See Kagel & Levin (2009), p. 1.
[131] See Wilson (1992), p. 230.
[132] See Klemperer (1999), p. 227; Chaturvedi et al. (2014), p. 1725.

tend to make strategic offers in the industrial purchasing environment.[133] Therefore, the application of mechanism design theory in negotiation design could help buyers to optimise the bidding behaviour of their suppliers.

Several consulting firms exist that support buying organisations in analysing competitive contexts and, based on the results, designing negotiation rules that aim at lowering purchasing prices. However, the discussion of mechanism design theory in the 'traditional' purchasing and supply management literature appears to be limited.

In order to get an overview of the state of the art in the purchasing related literature on mechanism design theory, relevant articles were identified through a search on Scopus. For the article collection, a query was developed, screening those articles published between the years 2000 and 2015, containing the terms "market design" or "mechanism design" in their title, abstract, or keywords. Additionally, the words "purchasing", "sourcing", or "procurement" had to appear in these parts of the articles in order to ensure the focus on the field of supply management. Further, the search was restricted to journals from the field of Business, Decision Sciences, Economics, Computer Science, Mathematics, and Social Sciences. As a result, 132 papers were identified that fit to the predefined criteria. Table A1 in the appendix displays a detailed list of all journals that have published articles meeting the search criteria.

As displayed in Figure 7, it appears that the papers are somewhat evenly distributed across different research areas. Even though the search terms were chosen in such a way that the papers had a supply management focus, the selected articles could neither be attributed to a specific research area nor to a specific set of journals.

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[133] See Scheffler (2015), p. 83; Scheffler et al. (2016), p. 572.

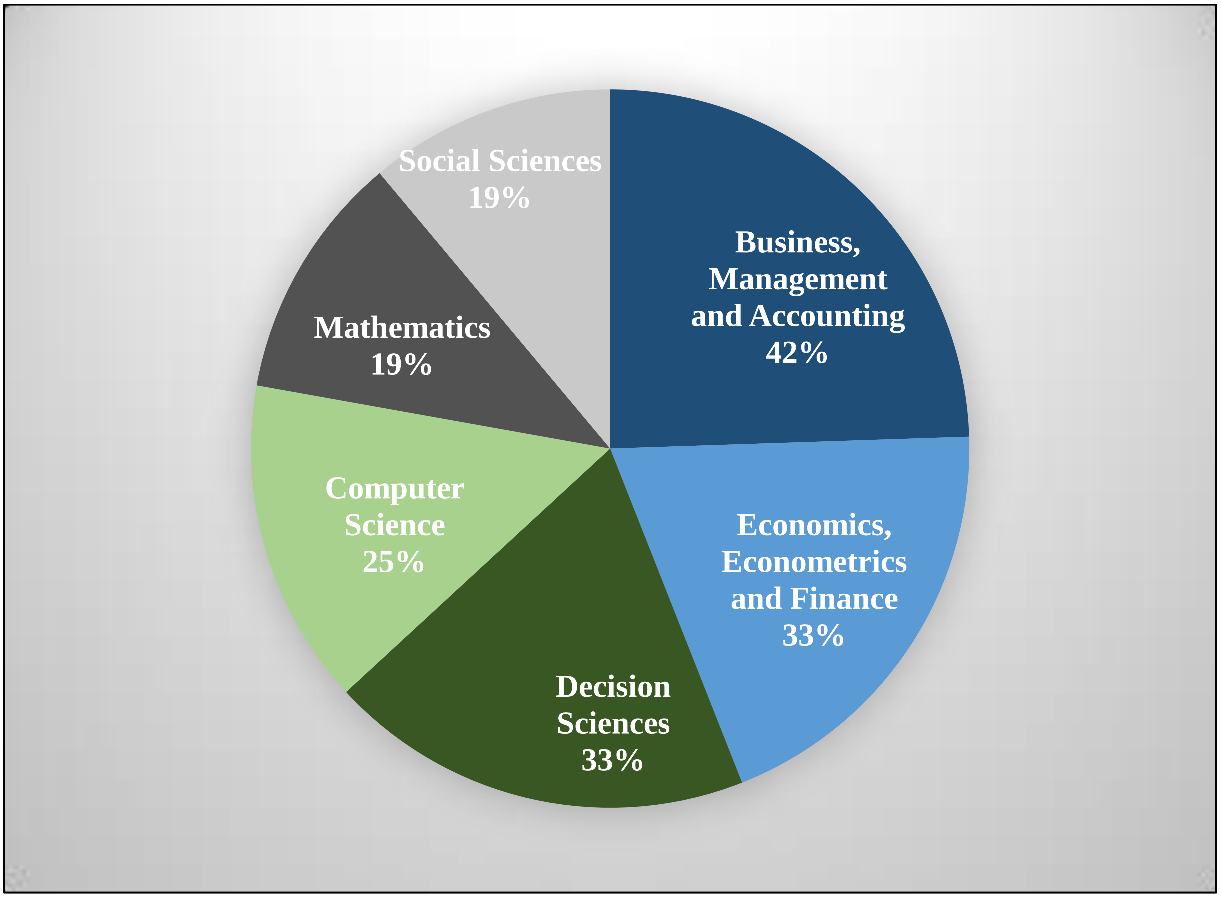

Figure 7: Distribution of papers across research fields
Source: Own elaboration

However, the journals "European Journal of Operational Research" (11), "Management Science" (9), "Games and Economic Behavior" (6), as well as "Electronic Commerce Research and Applications" (5) have five or more relevant publications within the timeframe under review and account for 23,5% of the papers identified.

In general, it can be concluded that despite the fact that mechanism design theory gains increased interest among purchasing managers, it is somewhat underrepresented in the scientific literature within the field of purchasing and supply management. This argumentation is further supported when taking a look at the list of journals that have published articles that fit to the predefined search criteria (see Table A1). Consequently, supply management literature should strive to catch up with the state of the art in purchasing practice. Making a first step to close this gap, the following sections describe the case study research at an automotive OEM with the aim to answer the four research questions of this study.

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Appendix

Journal Name	No. of Papers
European Journal of Operational Research	11
Management Science	9
Games and Economic Behavior	6
Electronic Commerce Research and Applications	5
Operations Research	4
Decision Support Systems	3
International Journal of Retail and Distribution Management	3
Journal of Economic Theory	3
Journal of Enterprise Information Management	3
Manufacturing and Service Operations Management	3
Review of Economic Design	3
Transportation Research Part B Methodological	3
Electricity Journal	2
International Journal of Housing Markets and Analysis	2
Journal of Economic Behavior and Organization	2
Journal of European Real Estate Research	2
Review of Economic Studies	2
Utilities Policy	2
B E Journal of Theoretical Economics	1
Business and Information Systems Engineering	1
Central European Journal of Operations Research	1
Econometrica	1
Economia Mexicana Nueva Epoca	1
Economic Journal	1
Economic Modelling	1
Economics Letters	1
Economie Et Prevision	1
Economists Voice	1
Energies	1
Euromed Journal of Business	1

Experimental Economics	1
Games	1
IEEE Transactions On Computers	1
IEEE Transactions On Smart Grid	1
Info	1
Information Systems Frontiers	1
Information Systems Research	1
Information Technology And Management	1
International Journal of Accounting and Information Management	1
International Journal of Game Theory	1
International Journal of Health Care Finance and Economics	1
International Journal of Information Technology and Decision Making	1
International Journal of Islamic and Middle Eastern Finance and Management	1
International Journal of Operational Research	1
International Journal of Operations and Production Management	1
Jahrbucher für Nationalokonomie und Statistik	1
Journal of Advanced Computational Intelligence and Intelligent Informatics	1
Journal of Applied Econometrics	1
Journal of Business and Industrial Marketing	1
Journal of Computer and System Sciences	1
Journal of Consumer Marketing	1
Journal of Convergence Information Technology	1
Journal of Economic Dynamics and Control	1
Journal of Fashion Marketing and Management	1
Journal of Information Processing	1
Journal of Management Information Systems	1
Journal of Mathematical Economics	1
Journal of Property Investment and Finance	1
Journal of Public Economics	1
Journal of Science and Technology Policy in China	1
Journal of The Association of Information Systems	1
Journal of The Operational Research Society	1
Lecture Notes in Computer Science including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics	1

Lecture Notes in Economics and Mathematical Systems	1
Marketing Intelligence and Planning	1
Marketing Science	1
Optimization Methods and Software	1
Performance Evaluation	1
Policy and Society	1
Quantitative Marketing and Economics	1
RAIRO Operations Research	1
Review of Law and Economics	1
Review of Quantitative Finance and Accounting	1
Service Industries Journal	1
Studies in Computational Intelligence	1
Supply Chain Management	1
Theoretical Computer Science	1
Tourism Review	1
Transactions of The Japanese Society for Artificial Intelligence	1
Wirtschaftsdienst	1

Table A1: List of journals and number of papers meeting search criteria
Source: Based on Scopus search