Relative Performance Evaluation in Executive Compensation

Investigating the Effects of Relative Performance Bonuses on Individual Strategies and Market Dynamics through an Experimental Approach

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Preface

This thesis, centred on exploring Relative Performance Evaluation (RPE) contracts within executive compensation, comprises three chapters, a comprehensive introduction, and a concluding discussion that synthesises findings and suggests future research directions. This thesis aims to critically examine and expand the understanding of the practice of RPE awards under the lens of experimental and theoretical frameworks.

In Chapters 2 and 3, I present self-contained empirical studies conducted with my supervisor, Prof. Dr Werner Bönte. Chapter 2 outlines an online study carried out during the COVID-19 pandemic using Prolific.com, while Chapter 3 presents findings from laboratory experiments conducted at the Econ Lab of the University of Wuppertal and the DICE Lab at the University of Düsseldorf. My role was central in these co-authored chapters. I originated the research questions, designed the experiments, oversaw the data collection processes, and conducted statistical analysis. I undertook the majority of the manuscript preparation, from articulating the research questions and scouting the relevant literature to constructing the arguments and points of discussion. In Chapter 2, I programmed the experiment in JavaScript/CSS/HTML, coordinated the experimental sessions, and managed communications with Prolific.com. For Chapter 3, my tasks additionally included coding the experiments using oTree, running the experimental sessions, and navigating the logistical and legal complexities of collaborating with the DICE Lab. For both studies, I conducted statistical analysis in R.

During our discussions, Prof. Dr Werner Bönte enriched the research with his methodological expertise and provided editorial input and feedback, ensuring the manuscripts met high academic standards. The ethical soundness of the experimental methodologies in Chapters 2 and 3 received approval from the University of Wuppertal's ethics committee. The Chair of Industrial Organisation and Innovation at the Schumpeter School of Business and Economics funded these studies.

Chapter 2, titled "Relative Performance Evaluation and Executive Compensation: Adding Fuel to the Fire," was presented at the University of Wuppertal's internal Brown Bag seminar and the 2023 Colloquium on Personnel Economics (COPE) at Vrije Universiteit Amsterdam. An earlier version of Chapter 2 was submitted to the Journal of Economic Behavior and Organization. Although the submission was unsuccessful, reviewers noted the "study to be interesting and useful" and that "the experiment was conducted in a very professional manner". Both reviewers have suggested that running additional experimental sessions in a simultaneous setting would strengthen the paper. Interestingly, the research presented in Chapter 3, which was conducted prior to this feedback, already incorporates some of the recommended aspects. Reflecting on the other comments received for the submission, reviewers suggested a more concise discussion and theoretical section. The current plan involves incorporating these changes to enhance clarity and focus before resubmitting to an alternative journal. However, it is worth noting that the current, more comprehensive version offers a broader and in-depth exploration of the subject, aligning better with the academic rigour expected of a doctoral thesis.

For Chapter 3, the immediate focus is conducting additional experimental sessions at the University of Wuppertal. This step is crucial for improving the publishability of the paper, ensuring the results are robust and the findings are well-substantiated. While we are open to refining the paper, the core structure and content are expected to remain largely unchanged. The strength of the existing analysis and the added depth from further data will solidify the paper's contribution to the field.

Chapter 4 makes a theoretical contribution to the research on Relative Performance Evaluation bonuses. Drawing inspiration from the current practices and examples of CEO compensation contracts, I introduce a novel conceptual framework and develop theoretical predictions currently unaddressed in the literature. In line with the overarching theme of this thesis, I also propose an experimental design aimed at testing these predictions. The experimental design is set for preregistration of the study.

This thesis represents a comprehensive journey through the intricacies of Relative Performance Evaluation in executive compensation, combining empirical research with theoretical innovation. It is my hope that this thesis will be a valuable contribution to the field, stimulating further scholarly discussion and practical application in executive compensation and corporate governance.

All remaining mistakes are my own.

Contents

List of Figures 3

List of Tables 4

1 General Introduction 5
1.1 Background and Motivation . . . 6
1.1.1 Foundational Concepts . . . 6
1.1.2 Existing Empirical Evidence . . . 8
1.1.3 Research Objective and Methodology . . . 9
1.1.4 Thesis Overview and Contributions . . . 11
1.2 Framework . . . 12
1.2.1 General Framework . . . 12
1.2.2 Thesis-specific Framework . . . 14
1.3 Chapter Overview . . . 15
1.3.1 Chapter 2 . . . 16
1.3.2 Chapter 3 . . . 17
1.3.3 Chapter 4 . . . 19

2 RPEs and Executive Compensation 21
2.1 Introduction . . . 22
2.2 Theoretical Framework . . . 24
2.3 Experimental Design . . . 29
2.3.1 Experimental Market . . . 29
2.3.2 Materials and Procedures . . . 31
2.3.3 Experimental Sample . . . 32
2.4 Experimental Results . . . 32
2.5 Discussion . . . 39
2.6 Conclusion . . . 43
Appendices . . . 45
2.A Tables . . . 45
2.B Challenges of Running Online Experiment . . . 46
2.C Additional Analyses . . . 47
2.D Instructions . . . 51

3 RPEs and Collusion 59
3.1 Introduction . . . 60
3.2 Theoretical Background . . . 62
3.2.1 One-shot Game: Symmetric and Asymmetric Manager Remuneration 63
3.2.2 Repeated Game: Symmetric Manager Remuneration . . . 65

3.2.3 Repeated Game: Asymmetric Manager Remuneration 66
3.2.4 Stability of Collusive Behaviour 67
3.2.5 Implicit and Explicit Collusion 69
3.3 Experimental Design 70
3.3.1 Market Setup 70
3.3.2 Methods 71
3.3.3 Sample 76
3.4 Experimental Results 77
3.4.1 First look at the Data 77
3.4.2 Hypothesis Testing 81
3.5 Discussion 87
3.6 Conclusion 90
Appendices 91
3.A Additional Tables 91
3.B Alternating Monopoly 93
3.C Experimental Instructions 97

4 RPEs without Competitors **119**
4.1 Introduction 120
4.2 Framework and Practical Implications 122
4.2.1 Formal Model 122
4.2.2 Comparative Statics 123
4.2.3 Specifications of the RPE Component 125
4.2.4 Practical Implications 126
4.2.5 Discussion 130
4.3 Empirical Validation 131
4.3.1 Experimental Design Proposal 133
4.3.2 Notes on Practical Implementation 138
4.3.3 Discussion 139
4.4 Conclusion 140
Appendices 141
4.A Calculations and Proofs 141
4.B Examples of RPE 143
4.C RPE Usage and Peer Group Type 145
4.D Possible Extension 146

5 Conclusion **147**
5.1 Summary 148
5.2 Implications 149
5.3 Limitations and Suggestions for Further Research 150
5.4 Closing Words 152

Bibliography **153**

List of Figures

1.1 Example of an RPE Award — Transocean, Ltd (2009) 14

2.1 Manager's Optimal Response Functions under APE- and RPE-based Compensation Schemes 27
2.2 Optimal and Observed Average Response Functions 33
2.3 Observed Behaviour for Different Leader Quantities 35
2.4 Observed Average Responses for Groups of Subjects with Positively and Negatively Sloped Response Curves 38

3.4.1 Average Observed Market Quantities for Different Combinations of Bonus Schemes and for C and NC Treatment 78
3.4.2 Density of Observed Collusion Indices 80
3.4.3 Share of the Markets that Achieved Joint Profit Maximisation 80
3.4.4 Share of Partially Collusive Markets 81
3.4.5 Devitiations from Collusive Agreements 86

4.2.1 Different Functional Forms 127
4.2.2 Illustrative Examples 128
4.2.3 Illustrations of Compensation Structures 128
4.3.1 Power Analysis 139

List of Tables

2.1 Estimated Linear Response Functions of Followers 34
2.2 Determinants of the Probability of Over-aggressive Behaviour: Logistic Regressions and Linear Probability Models 37
2.A.1 Demographics: Overall Sample and Subsamples 45
2.C.1 Estimated Linear Response Functions of Followers (including order effects) 47
2.C.2 Estimated Linear Response Functions of Followers (between-subject comparison) 47
2.C.3 Determinants of the Probability of Over-aggressive Behaviour: Logistic Regressions and Linear Probability Models (including order effects) . 48
2.C.4 Determinants of the Probability of Over-aggressive Behaviour: Logistic Regressions and Linear Probability Models (between-subject comparison) 48
2.C.5 Determinants of the Probability of Over-aggressive Behaviour: Additional Model Specifications (Logistic regressions) 49
2.C.6 Determinants of the Probability of Over-aggressive Behaviour: Logistic Regressions and Linear Probability Models (restricted sample analysis: only downward-sloping group) 50

3.2.1 Quantities, Profits, and Executive Compensation: Static Game . . . 65
3.3.1 Experimental Predictions for the Static Game 71
3.4.1 Observed Market Outcomes 78
3.4.2 Regression Analysis - Observed Quantities 82
3.4.3 Generalised Linear Mixed Models and Linear Probability Models: Cartels and Partial Collusion 84
3.4.4 Explicit Agreements and Deviation Analysis 85
3.4.5 Regression table: Deviations from Collusive Agreements 86
3.4.6 Profits and Compensation for each Contract Allocation 87
3.A.1 Demographics: Overall Sample and Subsamples 91
3.A.2 Regression Analysis - Observed Quantities (RPE as a factor) 92
3.A.3 Regression Analysis - Observed Quantities (RPE as a dichotomous variable) 92
3.B.1 Communication Treatment: Observed Cases of Alternating Monopoly 96

4.C.1 RPE Usage Statistics (2006-2017) 145

Chapter 1

General Introduction

"The use of thugs or sadists for the collection of extortion or the guarding of prisoners, or the conspicuous delegation of authority to a military commander of known motivation, exemplifies a common means of making credible a response pattern that the original source of decision might have been thought to shrink from or to find profitless, once the threat had failed. (Just as it would be rational for a rational player to destroy his own rationality in certain game situations, either to deter a threat that might be made against him and that would be premised on his rationality or to make credible a threat that he could not otherwise commit himself to, it may also be rational for a player to select irrational partners or agents.)"

Thomas Schelling - Strategy of Conflict (1960)

1.1 Background and Motivation

1.1.1 Foundational Concepts

The separation of ownership and decision-making has become a defining characteristic in modern organisations. Effective management is widely recognised as vital for business success (Finkelstein et al., 2009). However, this separation introduces distinct challenges, notably the issue of agency problems. Adam Smith, in his seminal work "The Wealth of Nations", was among the first to highlight this concern:

> "The directors of such companies, however, being the managers rather of other people's money than of their own, it cannot well be expected, that they should watch over it with the same anxious vigilance with which the partners in a private copartnery frequently watch over their own. Like the steward of a rich man, they are apt to consider attention to small matters as not for their master's honour, and very easily give themselves a dispensation from having it. Negligence and profusion, therefore, must always prevail, more or less, in the management of the affairs of such a company."
>
> — Adam Smith (1776) *An Inquiry into the Nature and Causes of the Wealth of Nations*, Book V: Chapter 1: Part III. Article 1.

A natural question at the heart of the observation by Smith is, thus, how best to ensure that managers' actions reflect the interests of the company's owners. Assuming the goal of the owners is to maximise profits[1] a straightforward solution is to tie executive compensation to the company's performance, thereby aligning the objectives of the managers and the owners. This idea of pay-for-performance is accepted as a primary determinant of executive compensation[2] and is implicitly assumed in standard economic models (Holmstrom and Tirole, 1989).

Although the pay-for-performance approach seemingly resolves the problems with separation of ownership and control, the advances in agency theory (see Bratton (2012)) over the past sixty years offer additional insights into how optimal executive compensation should be structured. More specifically, agency theory advocates including relative performance evaluation (further RPE) to complement pay-for-performance. Intuitively, contracts that include relative performance metrics tie the compensation positively to the performance of the manager's company and negatively to the performance of other companies. Broadly speaking, there are two theoretical perspectives on why profit-maximising

[1] This is a common approach in economic theory, e.g., Tirole (1988) or Lambertini (2017). Even more so, in some countries, this is a legal requirement for the company. For example, in Finland: "The purpose of a company is to generate profits for the shareholders unless otherwise provided in the Articles of Association"(LLC Act, Chapter 1.5). For a discussion of different objectives, see Sundaram and Inkpen (2004); Lankoski and Smith (2017) and the literature therein.

[2] See Edmans et al. (2021) for a review of the field data and Edmans et al. (2017) for empirical evidence.

owners may want to include relative performance considerations in remuneration decisions for executive management.

The first perspective considers RPE contracts as a way to accurately and efficiently extract (potentially unobservable) efforts from the agent (executive manager). For example, based on the informativeness principle (Holmstrom, 1979), an optimal contract should link an agent's pay to the outcomes directly under their control and to all available information that might provide insights into their effort and performance. Thus, including relative performance metrics can insulate risk-averse CEOs by filtering out industry-wide shocks (Gibbons and Murphy, 1990) and provide stronger incentives to extract effort (Lazear and Rosen, 1981; Gibbons and Murphy, 1990). A similar principle is used in the talent-retention hypothesis (De Angelis and Grinstein, 2020), which assumes talent is not fully observable.

Despite the benefits, one known concern associated with implementing relative performance payment schemes, especially at lower organisational levels, is the potential encouragement of sabotage and cooperative shirking behaviours (Lazear, 1989). Manifesting in various forms — ranging from withholding critical information to spreading false data or even deliberately damaging work tools — such sabotage is primarily aimed at undermining competitors' performance to elevate one's position (Harbring and Irlenbusch, 2011). In the context of executive compensation, Gibbons and Murphy (1990) suggest that CEOs "tend to have limited interactions with CEOs in rival firms, thus sabotage and collusive shirking seem unlikely". However, this assumption may not hold in imperfectly competitive markets. Indeed, in the context of oligopolistic markets, sabotage *between* the firms may take the form of sub-optimally low pricing, increasing output volumes excessively, or engaging in disproportionate advertising spending (Bloomfield et al., 2023). Although detrimental to the manager's firm, these strategies can inflict greater harm on peer firms, making them potentially more appealing to managers incentivised by the RPE-based bonuses.

While at first glance, owners might seek to discourage compensation schemes that misalign their objectives with those of their managers, a contrasting view emerges from the strategic delegation literature. This second perspective, far from seeing aggressive strategies as mere unintended consequences of RPE contracts, leverages them as a key mechanism to achieve a more dominant market position. Schelling (1960) noted that it might be "rational for a rational player to destroy his own rationality". Drawing on Schelling's insights, strategic delegation literature suggests that owners should deliberately incorporate non-profit maximising elements into their managers' incentive schemes. This surprising consequence of the separation of control and decision-making is developed in the seminal papers by Vickers (1985), Fershtman and Judd (1987), and Sklivas (1987). Van Witteloostuijn (1998) aptly termed this phenomenon the "profit maximisation paradox".

The underlying intuition behind the mechanism in strategic delegation lies in the idea that profit-maximising owners can *commit* to a more aggressive strategy by including bonuses based on metrics other than profits into their managers' contracts. In the duopoly situation, if one of the owners chooses to commit his firm to an aggressive strategy, his firm ends up with higher profits. If both owners use non-profit maximising components as part of their manager's contract, both firms end up with lower profits. In other words, the possibility of commitment leaves the owners in a prisoner's dilemma, where commitment is a dominant strategy. Earlier works focused on own-performance metrics like sales (Vickers, 1985; Fershtman and Judd, 1987) or revenue (Sklivas, 1987). Salas Fumas (1992) is the first[3] to explicitly look at the relative performance metrics with later works also analysing market share[4] (Ritz, 2008; Jansen et al., 2008). Works by Ritz (2008), Jansen et al. (2007) and Jansen et al. (2008) formally compare these approaches and find that using relative performance contracts (in particular, relative profits) is strategically superior to own-performance metrics, as competitor-oriented[5] objectives are less susceptible to external manipulation.

1.1.2 Existing Empirical Evidence

Regardless of the theoretical rationale behind their use, observational-level data shows that RPE bonuses are becoming widespread in modern companies. Early works did not find significant evidence of relative performance metrics in executive compensation. This phenomenon was broadly described as the "RPE puzzle" (Murphy, 1999; Prendergast, 1999). However, recent empirical studies present substantial evidence of the contrary. Following the changes in the disclosure policies mandated by SEC in 2006, Gong et al. (2011) show that over 25 per cent of all major US companies (S&P 1500) use explicit relative performance metrics in executive remuneration decisions. Bettis et al. (2018) contribute to this body of evidence by showcasing that nearly half (48%) of firms granting performance-based equity in 2012 incorporated at least one relative performance metric. Recent studies by Ma et al. (2019) and Bizjak et al. (2022) also indicate an upward trend in adopting the relative performance metrics.

The rising prevalence of relative performance bonuses in executive compensation brings discussions of their effects into sharper focus. Several studies have suggested that the effects of RPEs on product market strategies (i.e., increase in competitive levels) may explain firms' reluctance to use them, e.g., Aggarwal and Samwick (1999a), Gong

[3]Vickers (1985) have mentioned using relative profits as part of the managerial compensation contracts; however, Salas Fumas (1992) developed this idea further and was the first to refer to it as relative performance evaluation in the context of strategic delegation.

[4]Although it may seem that market share is an own-performance metric, achieving a higher market share *necessary* requires decreasing the market share of the competitors.

[5]Competitor-oriented incentives and relative performance contracts are often used synonymously in the strategic delegation literature. This substitution is possible because achieving a competitive advantage, as reflected in relative metrics such as profits or market share, inherently involves considering rivals' performance.

et al. (2011), and Vrettos (2013). The main evidence supporting these conjectures is the observed negative relationship between the level of industry concentration and the adoption of RPEs in firms, as noted in Bloomfield et al. (2023). In other words, these studies primarily focus on identifying the reason behind the use of RPE bonuses (or lack thereof) rather than establishing a causal relationship between RPEs and product market strategies.

1.1.3 Research Objective and Methodology

Put differently, despite the widespread use of RPE bonuses in executive compensation, there still exists a notable gap in academic research concerning their causal impact on managers' strategic choices. Investigating causal effects presents a challenge due to the following limitations inherent in observational data. Firstly, executive compensation has evolved into a highly intricate structure[6], encompassing fixed salaries, bonuses, stocks, stock options, and long-term incentive plans. These components may all be contingent on the firm's performance and relative performance (Bettis et al., 2018). Even with complete knowledge of the contract terms, isolating the impact of a specific element becomes practically unfeasible. Secondly, any decision about compensation is inherently dependent on firm-specific characteristics (for example, the competitiveness or nature of the markets, firm size, and number of competitors). This problem with endogeneity is emphasised in the report by Edmans et al.: "identifying causal effects of pay on firm behavior or performance requires instrumental variables or natural experiments that create quasi-random variation in executive pay. Given the nature of the pay-setting process, there are very few valid instruments that affect pay without also affecting the outcome variable of interest through some other channel (thus violating the exclusion restriction)" (Edmans et al., 2017, p.484). Lastly, the environments in which firms operate are not fully transparent. A comprehensive evaluation of CEO decisions from a strategic perspective requires complete access to firms' cost functions and demand estimates, which are often unavailable. Consequently, it is nearly impossible to establish a causal relationship between RPE awards and CEOs' actions from firm-level data.

The present thesis addresses this gap and contributes to understanding of the *causal* effects of RPEs on market strategies. Due to the challenges of using firm-level data, this thesis takes an experimental approach. The advantages of a controlled environment are significant. It enables full observability, simplifies the complexities inherent in real-world variables, and ensures that contract allocations are entirely exogenous. This method of analysing causal relationships is long established in industrial economics literature (Normann and Ruffle, 2011).

The research direction of this thesis is motivated by the empirical evidence of the use of

[6] So much so that compensation consultants are using Monte Carlo simulations to estimate grant values.

RPE-based bonuses rather than by theoretical motivations behind firm owners' choices to use them. Sengul et al. (2012) argues that strategic implications of managerial incentives are present regardless of whether these effects are intended (as in strategic delegation literature) or unintended (as in frameworks based on the informativeness principle). The studies in this thesis share this perspective. In other words, the subsequent chapters treat the RPE awards as exogenous and investigate the consequences of adopting them on top of the standard compensation schemes (i.e., absolute performance evaluations (APE)). Thus, the theoretical predictions in this thesis draw heavily on market stages in the strategic delegation models (Vickers, 1985; Salas Fumas, 1992; Jansen et al., 2008).

The thesis poses two research questions. The first question is:

What are the causal effects of Relative Performance Evaluation (RPE) bonuses on individual strategies of the managers?

Understanding the effects of RPE on individual strategies is of paramount importance for firms and incentive designers, particularly in light of the discourse in management literature with regard to "competitive irrationality" (Arnett and Hunt, 2002). Competitive irrationality[7] is a tendency of managers to sacrifice the absolute profits of their company only to improve their relative competitive standing (Graf et al., 2012). In other words, managers choosing aggressive product market strategy (for example, elevated levels of output or sub-optimally low prices) even without any additional incentives is a well-known phenomenon[8]. RPE-based awards provide explicit incentives to behave spitefully (which may or may not be intended by the contract designers). Thus, if managers over-react to these incentives, it may become detrimental for the firms to use RPE awards, as managers would sacrifice absolute profits beyond what is theoretically predicted to improve their relative position.

The second research question is:

What are the causal effects of the presence of Relative Performance Evaluation (RPE) bonuses on market outcomes?

The second question is the direct extension of the first one. If the RPEs indeed encourage aggressive behaviour, they inadvertently affect firms' profits and the overall level of competition in the market. The latter consequence is of particular relevance for policy-makers. Currently, government bodies advocate for the use of RPEs as a tool

[7]Note, this is a term used in the Management research literature. From economists' perspective, many behaviours deemed "irrational" can be justified by specific objective functions. In this instance, competitive irrationality is better described as non-compensation maximising behaviour.

[8]For example, in a number of laboratory studies with over a thousand subjects, Armstrong and Collopy (1996) found 40 per cent of the participants were willing to sacrifice part of their company's profits to beat or harm the competitor. Even more peculiar, they report that management education increases the probability of choosing less profitable decisions. Griffith and Rust (1997) present similar findings in pricing decisions of MBA students under Bertrand competition environment.

to improve shareholder value (Farmer et al., 2013). However, if RPE awards make the markets more competitive, they can also be used as a tool by anti-trust authorities. This potential of RPE bonuses to intensify market competition highlights the relevance of this research direction not just in the realm of corporate governance but also in broader economic policy for enhancing allocative efficiency.

1.1.4 Thesis Overview and Contributions

Chapters 2 and 3 feature self-contained experimental studies. Chapter 2 focuses on the effects of the RPE bonuses in a static environment. The design of the experiment in Chapter 2 is particularly well-suited for analysing the changes in individual strategies, i.e., for testing the core mechanism behind the RPE awards in strategic environments. Thus, Chapter 2 is directed primarily at answering the first research question. Chapter 3 explores the effects of RPE bonuses in a dynamic (repeated) setting, focusing on the market consequences and allocative efficiency. Additionally, this chapter investigates the role of RPE awards in environments where explicit agreements are possible, examining RPEs' potential as tools for mitigating cartel stability. Chapter 4 offers a novel theoretical insight, which is inspired by ongoing debates regarding the practices of relative performance evaluation bonuses. However, continuing the leitmotif of the thesis, Chapter 4 also proposes an experimental design to test its theoretical conclusions. Consequently, each chapter advances the thesis's research direction, examining RPE bonuses across various strategic contexts and scenarios. In doing so, the thesis, as a whole, contributes to several distinct strands of literature.

First and foremost, the thesis provides empirical evidence on the effects of RPE awards in the context of imperfectly competitive markets, supplementing the studies based on observational data, e.g., Aggarwal and Samwick (1999a), Gong et al. (2011), Vrettos (2013), or Bloomfield et al. (2023).

Second, the thesis contributes to experimental literature on strategic delegation by establishing a causal relationship between RPE bonuses and product market strategies. Unlike previous studies which examine other remuneration schemes, such as sales bonuses (Huck et al., 2004a; Kim, 2022) or revenue bonuses (Du et al., 2013), this thesis focuses specifically on the RPE awards. In contrast, previous studies concentrate on the owners' decisions (i.e., whether to adopt a certain incentive), thus suffering from potential endogeneity problems. In contrast, this thesis treats the RPE contracts as exogenous, as they may be introduced for other (non-strategic) reasons. Thus, experimental studies in this thesis aim to demonstrate causal effects.

Third, by analysing the effects of RPEs on market outcomes in dynamic environments, the thesis also offers new perspectives to the extensive body of research on market efficiency, tacit collusion, and cartel stability (Engel, 2007, 2015). Chapter 3 presents empirical evidence that RPE bonuses can make the markets more competitive and have the potential to destabilise explicit cartels. Unlike existing experimental works that primarily focus on factors external to the firm (i.e., number of firms, type of competition, product heterogeneity among many others[9]), this thesis looks at internal factors, similar to recent experiments by Kim (2022) and Fonseca et al. (2022). Furthermore, Chapter 4, inspired by the practices in executive compensation, posits that *some* RPE awards may encourage collusion. The theoretical foundation for this conjecture is similar to Spagnolo (1999) and Spagnolo (2005), yet is unaddressed in the current literature on RPE awards.

Lastly, the findings in this thesis add to an emerging field of Behavioural Agency Theory (Pepper et al., 2019). Behavioural Agency Theory proposes a new approach to principal-agent relationships that builds upon the recent advances in behavioural economics and psychology. In the context of managerial compensation, Pepper et al. (2019) argues that managerial decision-making is affected by both extrinsic motivations (for example, explicit monetary incentives like RPE awards) and intrinsic motivations (for example, being spiteful as in Fehr et al. (2008)). These motivations are neither independent nor additive (Pepper and Gore, 2012). In other words, when designing incentives, it is important to consider their *behavioural* effects. Results in Chapter 2 show that RPE awards amplify intrinsic preferences to behave "competitively irrationally", validating the ideas described in Behavioural Agency Theory.

1.2 Framework

Before going into further details about the methodology and contributions of each chapter, it is first essential to look at the general framework, its underlying assumptions and the extent to which these assumptions align with RPE bonuses observed in practice.

1.2.1 General Framework

Broadly, managerial compensation (v_i) can be represented by the following form:

$$v_i = w_{fixed} + f_{own}(\pi_i) + f_{rpe}(\pi_i, \pi_k, ...) \tag{1.1}$$

Where w_{fixed} is the fixed salary of the executive manager, π_i is the firm's performance (for example, the simplest measure of performance is profits), $f_{own}(\pi_i)$ is the pay-for-performance component, and $f_{rpe}(\pi_i, \pi_k, ...)$ is the relative performance component.

The fixed salary is the least important component as it does not affect strategic decision-making. Empirical evidence further reflects this conclusion, with fixed salary accounting for only 13 per cent of total executive compensation (Edmans et al., 2017). In fact, it is not uncommon for CEOs to forgo their fixed salary altogether. For example, CEOs of growing firms would often choose a one-dollar salary as a signal for high hopes about future performance (Hamm et al., 2015).

[9]See Feuerstein (2005b); Potters and Suetens (2013); Engel (2015) for review of existing experimental studies.

The second element of executive salary is positively related to the firm performance (π_i), capturing concerns from the observation by Adam Smith. Empirical studies mostly[10] agree that improved performance results in higher compensation for executive managers and has high pay-performance sensitivity (Hall and Liebman, 1998). Although going into exact details of executive managers' individual compensation is beyond the scope of this thesis, there are few typical elements of CEO compensation packages that can illuminate this mechanism[11]. First, CEOs are commonly minority stockholders in their company, implying that increased performance (like profits) is also partly distributed to them. Second, most compensation packages include performance bonuses with either stock, options or cash, further contributing to pay-performance sensitivity.

The third element of managerial compensation is the focus of this thesis. Broadly, $f_{rpe}(\pi_i, \pi_k, ...)$ depends positively on the performance of the manager i's company and negatively on the performances of K other companies that form the reference peer group. Including this element allows for *evaluation* of the manager's performance relative to the performances of other K companies. Many dimensions of RPE bonuses differ from firm to firm.

Early reports by Bannister et al. (2010) showed that three-quarters of S&P 500 companies used accounting-based measures (i.e., profits, sales or revenue). Contemporary studies indicate that market-based performance measures like relative total shareholder return are used more often[12] (Ma et al., 2021).

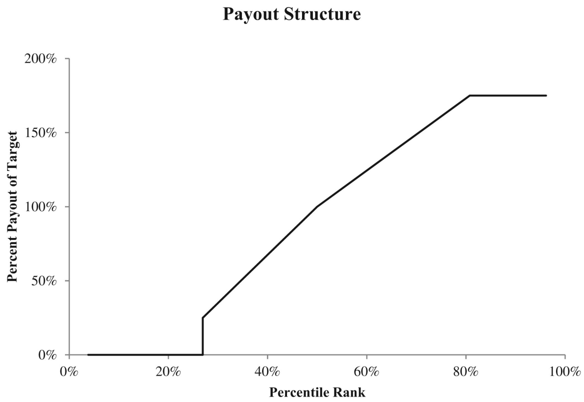
The way *outperforming* peer group firms (i.e., K firms) increases CEO reward is also different. The majority of companies use rank-order tournaments similar to Lazear and Rosen (1981), where the performance of all $K + 1$ firms is ranked. The manager is rewarded based on the relative rank of his company. An example (from Bizjak et al. (2022)) of a payment scheme is shown in Figure 1.1. Around 14 per cent of the companies (Angelis and Grinstein, 2019) use a distance measure - where the manager is rewarded based on the distance to the average performance of peer group companies.

Lastly, an important dimension of the RPE awards concerns the selection of the reference peer group. Analyses by Albuquerque (2009), Gong et al. (2019) and Bizjak et al. (2022) show significant heterogeneity in how these peer groups are constructed. From the risk-sharing perspective (i.e., according to the informativeness principle), selecting firms in the same industry is the most beneficial since firms in the same industry are more likely to suffer from the same exogenous shocks. Therefore, as noted in Bloomfield et al. (2023), the peer groups would often contain firms that are direct competitors. However,

[10] For a discussion, see Bebchuk et al. (2002), who describe arguments in favour of the view that managers possess significant power over their own compensation and can, therefore, be paid without concerns for their firm's performance.

[11] For a more comprehensive review, see Murphy (2013).

[12] For example, De Angelis and Grinstein (2019) report that only 35 per cent of the companies use accounting-based measures - indicating the ongoing evolution of the RPE awards.



RPE Custom Peer Group
Baker Hughes Inc.
Diamond Offshore Drilling Inc.
ENSCO International Inc.
Halliburton Co.
Nabors Industries Ltd.
National-Oilwell Varco Inc.
Noble Corp.
Pride International, Inc.
Rowan Companies Inc.
Schlumberger Ltd.
Smith International, Inc.
Weatherford International Ltd.

Payout Function		
Rank	Percentile Rank (%)	Target Multiplier (%)
11–13	0–27	0
10	27	25
7	50	100
1–3	81–100	175

Figure 1.1: Example of an RPE Award — Transocean, Ltd (2009) from (Bizjak et al., 2022)

this is not always the case, and the RPE awards may use a broad market index (e.g., S&P 500 or S&P 1500) or choose companies that are similar in size but are not direct competitors (Ma et al., 2021).

Regardless of the exact details of the RPE award, the underlying concept remains consistent: if the performance of the reference group companies is relatively lower than the performance of the managers' company, the manager receives a higher bonus. Do et al. (2022) report that outperforming the peer group, on average, results in a 4.2 million USD pay increase - a significant part of the median CEO compensation of 7.2 million.

1.2.2 Thesis-specific Framework

As with any experimental analysis, this thesis makes several simplifying assumptions. Throughout Chapters 2-3, managerial compensation is assumed to be:

$$v_i = w_{fixed} + \pi_i + \gamma(\pi_i - \pi_{-i}) \tag{1.2}$$

Where w_{fixed} is a fixed payment, π_i is the company i's profits, π_{-i} is the profit of the direct competitor $-i$ and $\gamma > 0$ is the weight of relative performance component.

The first component (w_{fixed}) is the same as in the Eq. 1.1. Both chapters assume the performance metric to be the company i's profits. Although the general framework does not assume f_{own} to be linear in performances, maximising π_i results in maximising $f_{own}(\pi_i)$, as f_{own} is monotonically increasing in π_i. In other words, from the perspective of strategic action space, this simplification realistically corresponds to what is observed in practice.

With regard to the relative performance evaluation component (i.e., $\gamma(\pi_i - \pi_{-i})$), there are several notes. First, this specification preserves the overall direction of the effects of performances (profits) of firm i and firm $-i$. Second, although the main reason behind the linear relationship is improved tractability and ease of understanding for experimental subjects, RPE measures based on the distance and accounting measures (as described in the previous subsection) are also observed in real-world contracts[13]. Additionally, this representation is commonly assumed in empirical works on RPE, e.g., Aggarwal and Samwick (1999a) or Vrettos (2013).

Lastly, the key assumption in Eq. 1.2 implies only one firm in the reference peer group, a direct competitor of firm i. Angelis and Grinstein (2019) show that 40 per cent of the peer group companies belong to the same 4-digit SIC (Standard Industrial Classification) code as the firm of interest[14]. In other words, peer groups often contain firms in the same industry, i.e., direct competitors. Therefore, this assumption is fairly realistic for concentrated industries and relatively small reference peer groups.

If some peer group companies operate in a completely different industry, the manager of firm i cannot meaningfully influence their performances. The latter is not true for direct competitor companies in the peer group, similar to the frameworks previously described in strategic delegation literature (Vickers, 1985; Jansen et al., 2008). Including RPE bonuses that contain competitors influences how the manager of firm i chooses his product market strategies. Chapters 2 and 3 focus specifically on these implications.

Chapter 4 uses a more general framework and does not assume any specific form of the RPE component but preserves the underlying concept of the bonus increasing with the performance of the firm in question and decreasing with the performances of all other firms in the reference group. In this approach, at least intuitively, if the reference peer group of manager i does not involve any competitors or is relatively large (for example, if the RPE award is using a broad index as a benchmark), the strategic choices of the manager of firm i should not change. This intuition is implicitly assumed in most studies that analyse the relation between RPE and product market competition. Chapter 4 challenges this perspective and describes a situation where including an RPE award that does not involve direct competitors may push managers towards a more collusive outcome.

1.3 Chapter Overview

The subsequent chapters are structured as autonomous studies and contain individual hypotheses, background literature reviews, methodology, and contributions. However, the presented studies are connected by the broader research questions and the underly-

[13] Additionally, even with a rank-order tournament structure, if the profits of the company $-i$ are observable with some level of noise that is normally distributed, the relationship between RPE grant value and the profits of firm π_{-i} can be, at least partly, approximated by a linear relationship.

[14] Around 70 per cent belong to the same Fama–French 48 industry classification as the firm.

ing thesis-specific framework. More specifically, each chapter presents different strategic environments where the implications of the thesis-specific framework are investigated.

I now provide an overview of each chapter and respective methodologies and contributions.

1.3.1 Chapter 2

Chapter 2, titled "Relative Performance Evaluation and Executive Compensation: Adding Fuel to the Fire", starts the overarching theme of the thesis by comparing the effects of the compensation schemes that include the Relative Performance Evaluation (RPE) component to those that only rely on the Absolute Performance Evaluation (APE).

The study's primary aim is to test the underlying mechanism behind the RPE awards, namely the change in individual response functions. Including a relative performance component (as described in Section 1.2) that uses a direct competitor as a benchmark encourages more aggressive product market choices. In the context of a quantity-setting duopoly, a manager under the RPE contract would select higher quantities for any possible choice of his competitor than under the APE contract. From the perspective of the profit-maximising firm (or a manager under the APE contract), elevated quantity choices would mean that the firm's profits are lower for any specific choice of the rival firm. However, from the perspective of the compensation-maximising manager, there are explicit incentives to engage in such behaviour. If the motivation for the use of the RPE is to commit to a more aggressive strategy (as in strategic delegation literature (Vickers, 1985; Salas Fumas, 1992; Jansen et al., 2008)), then some level of misalignment between the response functions of a compensation-maximising manager and a profit-maximising firm is intended[15]. However, even in this interpretation, if the inclusion of the RPE awards results in higher frequencies of *over*-aggressive behaviour (i.e. managers sacrificing their *compensation*), then firms' profits suffer even more than theoretically predicted. Thus, the secondary aim of the study is to analyse whether RPE-based contracts increase the likelihood of observing over-aggressive behaviour.

To fulfil the study's objectives, my co-author and I conducted an online experiment. Acting as firm managers in a Stackelberg duopoly, participants were tasked with choosing production quantities. The experiment employed the strategy method, as described by Brandts and Charness (2011). In other words, each participant, assuming the role of a Stackelberg follower, formulated response plans by choosing production levels in reaction to all potential decisions made by the Stackelberg leader. Subjects created their response plans under both RPE and APE compensation schemes. This design enabled both within-subject analysis for the entire sample and between-subject analysis for a subset of subjects with primary exposure to treatment. Most importantly, the strategy method allowed the

[15]In contrast, for the frameworks based on the informativeness principle, any deviation from the profit-maximising market strategy is a negative side effect.

comparison (between compensation schemes with and without the RPE component) to be made on the entire response functions rather than on individual observations.

The experimental results point to a causal effect of the RPE-based compensation scheme on quantity decisions: subjects opt for higher quantities when incentivised by the RPE-based compensation scheme. In other words, the experiment provides conclusive empirical support for the basic mechanism behind the strategic effects of the RPE awards. However, while this observation is consistent with theoretical predictions, the data implies that subjects deviate from payoff maximisation under both compensation schemes. In particular, the findings indicate that the compensation system that includes RPE significantly raises the probability of individuals sacrificing their own compensation in an attempt to diminish their competitors' earnings (i.e., behaving over-aggressively).

The study contributes to several strands of literature. As discussed in the subsection 1.1.4, the study is supplementary to the current works on RPEs that look into observational firm-level data. Additionally, the study provides a more detailed account of the causal relationship between RPEs that include direct competitors and product market strategies, adding further insights to the literature on strategic delegation. The observed over-aggressive behaviour is a direct instance of being competitively irrational, i.e., sacrificing one's compensation to hurt the competitor. In this way, the study can also be seen as a contribution to the body of work on "competitive irrationality" (e.g., Graf et al. (2012); Graf-Vlachy (2021) and "costly sabotage" (e.g., Harbring et al. (2007); Harbring and Irlenbusch (2011)).

1.3.2 Chapter 3

Chapter 3, titled "The Impact of Relative Performance Evaluation in Executive Compensation on Market Efficiency and Collusive Behaviour", continues the theme of the thesis by considering the effects of the RPE awards in a dynamic environment. In contrast to Chapter 2, which focuses on the effects on individual managers, Chapter 3 examines the market efficiency implications of the RPE awards.

The study employs infinitely repeated Cournot duopoly as its framework. Theoretical models in Matsumura and Matsushima (2012) and Guigou and de Lamirande (2015) suggest that in this setting, RPE-based contracts would improve market efficiency in two ways. First, as in Chapter 2, RPE contracts would result in more aggressive strategies than APE contracts. Although more intense competition in a static game increases rewards from cooperating on the market level, as discussed in Lundgren (1996), RPE-based compensation also increases the managerial incentive to deviate from any cooperative outcomes. Thus, the second channel is that both tacit and explicit collusion would be less stable under RPE-based compensation than under APE-based compensation. This premise has not yet been empirically shown.

An economic experiment was conducted to test these theoretical conclusions. The experiment took place in the Econ Lab (University of Wuppertal) and the DICE lab (University of Dusseldorf). Participants engaged in a repeated duopoly, making quantity decisions as managers. The experiment varied in two main aspects: the type of compensation and the possibility of communication. Participants' rewards were determined by either Absolute Performance Evaluation (APE) or Relative Performance Evaluation (RPE) bonuses. The experiment was organised as a series of supergames. In total, participants played four supergames: two under each compensation scheme. This setup enabled the analysis of market outcomes across all bonus combinations (APE vs. APE, APE vs. RPE, RPE vs. APE, and RPE vs. RPE). The second variable concerned communication: in one scenario, participants could coordinate their strategies through chat before each supergame, while in the other, no communication was permitted. The analysis of chat messages in the communication scenario provided insights into the formation of collusive agreements and participants' choice to deviate from these agreements during the experiment.

The experimental results reveal that, without communication, RPE-based contracts improve market efficiency by increasing output. The chosen output levels increase even if only one of the two managers receives RPE-based compensation. The results also show that both firms' profits decrease due to RPE-based compensation, regardless of whether one or both firms use it. However, RPE-based pay has no significant effect on the rate of explicit collusion, as the majority of the markets were able to achieve collusive agreements. Hence, the results confirm existing experimental studies that have also shown the importance of communication for collusive behaviour (Fonseca and Normann, 2012; Hanaki and Ozkes, 2022). The effect of communication is strong enough to weaken the pro-competitive effects of RPE on allocative efficiency. However, based on the current data, there is some suggestive evidence that RPE contracts provide sufficient incentives for deviation after reaching the agreement.

The study's primary contribution is to the literature on tacit collusion and cartel stability (Engel, 2007, 2015). Unlike previous experimental works in this area, the study looks at internal factors as possible determinants of the level of competition in the market. The experiment is the first to examine the causal effect of RPE-based awards on the stability of explicit agreements. The results of the study have direct policy implications. Currently, government bodies advocate for the use of RPEs as a tool to improve shareholder value Farmer et al. (2013). However, the experimental results reported in Chapter 3 show that RPEs can also be used as a pro-competitive device, improving allocative efficiency and potentially destabilising cartel agreements. However, the RPEs should explicitly include direct competitors to achieve this.

1.3.3 Chapter 4

Chapter 4, titled "Relative Performance Evaluation in Executive Compensation May Encourage Collusion: Why Details Matter", diverges from the frameworks of Chapters 2 and 3, which focus on Relative Performance Evaluations (RPEs) with direct competitors as reference benchmarks. Instead, it examines RPE contracts utilising non-competitor peer groups or broad indices (for example, S&P 500 or S&P 1500) for benchmarking. Empirical studies, e.g., Bizjak et al. (2022); Bloomfield et al. (2023), suggest that company owners adopt this approach to mitigate the negative impacts on profitability from the heightened competition (demonstrated by experimental evidence in the earlier chapters). Furthermore, Ma et al. (2021) mentions that some compensation consultants suggest this approach to companies.

Chapter 4 consists of two parts. The first part presents a theoretical model which explores the strategic implications of RPE awards that do not include direct competitors. The theoretical framework considers a generalised model of an infinitely repeated duopoly and compares scenarios where managers' contracts include RPEs against those where compensation is solely based on the company's own performance metrics. The analysis demonstrates that RPEs increase the gains from collusion and may also make collusive behaviour easier to sustain. The chapter then derives specific conditions under which this holds true and examines the extent to which these conditions are observed in commonly used compensation contracts.

The predictions of the theoretical model highlight the necessity for a more critical discussion of current practices in RPE awards due to their potential to induce collusion. However, as the model concentrates only on the strategic aspect of the RPE-based compensation, validating its findings poses significant practical challenges, particularly if based on observational firm-level data. Thus, as a preliminary step, the second part of the chapter outlines the design of a controlled economic experiment to test its predictions. It provides a comprehensive description of the experimental treatments, formulated hypotheses, procedures, and the analytical approach to be employed. As part of this proposal, Chapter 4 also provides a power analysis. This emphasis on experimental design rather than results is a direct response to a growing trend towards pre-registration and pre-analysis plans in economic research, aimed at enhancing transparency and methodological integrity.

Broadly, the concerns raised in Chapter 4 are largely overlooked in recent empirical literature. Although the model serves primarily as an illustration of the potential mechanism, its implications are nonetheless concerning for anti-trust authorities and policymakers. Confirming these theoretical predictions in a controlled experiment would ideally invite further discussions and empirical analyses. Consequently, the proposed experiment could broaden the collective understanding of the current practices in executive compensation and potentially inform future policy and regulatory decisions in the field of executive compensation.

Chapter 2

Relative Performance Evaluation and Executive Compensation: Adding Fuel to the Fire†

Abstract
In this experimental study, we compare the effects of a compensation scheme based on Relative Performance Evaluation (RPE) and a compensation scheme based on Absolute Performance Evaluation (APE) on decision-making in a market game. To this end, we conduct an online experiment using the strategy method to obtain individual responses in a duopoly market with quantity competition. Our results point to a causal effect of the RPE-based compensation scheme on quantity decisions: subjects opt for higher quantities when incentivised by the RPE-based compensation scheme. While this observation is consistent with the theoretical predictions, our data imply that subjects deviate from payoff maximisation under both compensation schemes. Specifically, we find strong evidence that the RPE-based compensation system, in particular, increases the likelihood that subjects sacrifice their payoffs to reduce the competitors' payoffs (i.e. behave *over*-aggressively). Our results suggest that RPE-based remuneration structures, which are gaining traction in practice, may have unintended behavioural effects and can be detrimental to the profits of firms that use them.

† *Co-written with Werner Bönte. We express our gratitude to the participants of the 25th Colloquium on Personnel Economics (COPE) and a research seminar at the Schumpeter School of Business and Economics for their invaluable insights and constructive feedback on our paper.*

2.1 Introduction

Performance-based compensation for managers is ubiquitous in companies today. Generally, business owners can take two approaches in designing these incentive contracts. In the first approach, managers are compensated solely based on the absolute performance of their company, e.g., based on its profit. In the second approach, the manager's remuneration is competitor-oriented and includes metrics of the relative performance of the manager's company compared to competitors. While earlier studies concluded that compensation systems based on relative performance evaluation (RPE) are rare (Murphy, 1999; Aggarwal and Samwick, 1999a) — a fact which has come to be known as the "RPE Puzzle" — more recent studies suggest that these types of bonus systems have become significantly more common. According to Feichter et al. (2022), the use of RPE more than doubled between 2006 and 2019, and Bizjak et al. (2022) report that more than half of S&P 500 companies currently use some form of RPEs in their executive compensation.

Economic theory provides two main justifications for firm owners to include competitors' performance in remuneration decisions for their managers. The first theoretical argument for using RPE in managerial compensation is rooted in the idea that managers' activities and efforts are often difficult to observe and verify, resulting in asymmetric information between the owners and their managers. Theoretical studies show that relative performance evaluations allow for a better assessment of managers' efforts from the shareholders' perspective (Gibbons and Murphy, 1990), can insulate managers' compensation from industry-related shocks (Holmstrom, 1979), and enable talent retention (Angelis and Grinstein, 2019). The second theoretical argument comes from the literature on "strategic delegation" and states that business owners can use RPE-based bonuses to induce managers to behave more aggressively, thus putting competitors in a disadvantageous position. Under certain conditions, a firm's commitment to an RPE-based contract can increase its profits (Vickers, 1985; Jansen et al., 2008). Despite the widespread use of RPE in practice and the theoretical arguments in its favour, our knowledge of how this form of executive compensation affects managerial behaviour is still limited.

This chapter empirically examines how managerial behaviour is affected by RPE-based payment schemes compared to compensation based on an absolute performance evaluation (APE). In particular, we argue that remuneration systems based on RPE may influence managers' behaviour in ways that have unintended negative consequences for their companies. For example, Armstrong and Green (2007) find that competitor-oriented objectives are associated with reduced profitability of firms, providing indirect empirical evidence of the potentially harmful effects of RPE on firms' performance using this form of executive compensation. However, it remains unclear whether the observed negative correlation between performance and RPE is due to the individual behaviour of managers incentivised by RPE or other unobserved factors. More specifically, previous research has not empirically examined the causal effects of RPE bonus systems on individual managerial behaviour. This study argues that by rewarding their managers through an RPE-based compensation system, companies may harm their bottom line as managers who already compete aggressively on their own may overshoot the mark. Indeed, existing empirical evidence suggests that managers' mere knowledge of competitors' profits is sufficient to trigger aggressive behaviour (Armstrong and Green, 2007). For example, Armstrong and Collopy (1996) conducted a laboratory study with 1016 subjects and found that 40 per cent of the subjects were willing to sacrifice part of their company's profits to beat or harm the competitor when information about the competitor's profit was provided. Griffith and Rust (1997) present similar results for a prisoner's dilemma pricing experiment. Griffith and Rust explicitly instructed and incentivised subjects to maximise profits, yet subjects tended to value relative performance compared to competitors. Against this background, one can expect the competitor-oriented compensation systems based on the evaluation of relative company performance (RPE) to further escalate the aggressive behaviour in managers.

To determine the causal effect of RPE-based compensation systems on managerial behaviour, we conduct an online (lab-in-the-field) experiment. In this experiment, we use a market game where participants decide which quantities to produce in a Stackelberg duopoly. To this end, we use the strategy method (Brandts and Charness, 2011) to elicit participants' strategies. Specifically, each subject creates response plans as a Stackelberg follower by selecting production quantities for possible choices of the Stackelberg leader. Subjects make their decisions under both RPE and APE compensation systems. This design enables us to conduct both within-subject analysis for the entire sample and between-subject analysis for a subset of subjects with primary exposure to treatment. Overall, our methodology allows us to identify the causal effect of RPE-based contracts. To the best of our knowledge, our study is the first experimental study to focus exclusively on the behavioural implications of RPE-based compensation systems on managers' strategies.

We find a positive causal effect of the RPE compensation system on the quantity chosen by the subjects, implying that this form of incentive leads to more aggressive behaviour than the APE compensation scheme. For most subjects, we observe downward-sloping response curves that are affected by the RPE environment in the manner predicted by theoretical considerations (Vickers, 1985; Salas Fumas, 1992; Aggarwal and Samwick, 1999b; Jansen et al., 2008). However, our results also suggest that the RPE-based compensation system has a stronger negative effect on own-company profits than the theory predicts. Even more peculiar, we find a positive causal effect of the RPE compensation system on the probability of sacrificing *own remuneration* (and not just profits of one's company) to harm competitors.

Studies closest to our work examine the effects of competitor-oriented objectives and information on managerial decisions and profitability (Armstrong and Collopy, 1996; Armstrong and Green, 2007; Griffith and Rust, 1997). In contrast to experimental studies in this area, which examine how information about competitors' performance affects managerial decisions, subjects in our experimental design always receive information about competitors' profits, and competitors' profit directly affects the payoff of subjects under the RPE compensation scheme. By varying only the type of contract but not the information, confounding problems are avoided, which allows us to identify the causal effect of RPE- and APE-based compensation systems on quantity decisions. In addition, our experimental design is based on an economic model that allows us to compare the observed quantities or response curves with the best response curves derived from the theory, i.e., assuming that managers maximise their compensation.

Our study is also related to experimental studies in the field of "strategic delegation". The works in this area are mainly concerned with the perspective of business owners and their choices of specific managerial compensation schemes[1]. In these experiments, the type of manager compensation is an endogenous choice variable; thus, the causal effect of compensation schemes on the individual behaviour of managers can hardly be analysed with previous designs. In contrast, we aim to investigate how the managers react to specific compensation schemes; therefore, the type of compensation scheme is an exogenous treatment in our experimental setting. Additionally, existing experimental studies in the field of strategic delegation do not examine managerial compensation schemes based on RPE but focus on compensation schemes based on APE (like sales)[2]. Our results align with some of the findings reported in experiments on strategic delegation, but we extend existing work by investigating the causal effects of compensation schemes on individual decision-making.

The remainder of this chapter is organised as follows. Section 2 presents our theoretical framework and testable hypotheses. Section 3 explains the experimental design and implementation. Section 4 reports the results, and Section 5 provides a discussion of the results. Conclusions and suggestions for future research are provided in Section 6.

2.2 Theoretical Framework

The remuneration structure for managers has long evolved beyond fixed salaries, which by 2014 accounted only for 13 per cent of the total CEO compensation in S&P 500 (Edmans et al., 2017). Currently, managerial compensation consists of various stimuli, including stocks, options, bonuses and long-term incentive plans. Previously, these stimuli depended on the length of tenure (the so-called time-vesting). Today, performance-based vesting and bonuses are significantly more dominant (Bettis et al., 2018). Thus, without

[1]See Huck et al. (2004a); Georgantzís et al. (2008); Du et al. (2013)

[2]The only exception is the work of Georgantzís et al. (2008). Their work also focuses on the commitment of firm owners to an RPE-based compensation scheme and, thus, suffers from endogeneity problems with regard to the analyses of managerial decisions.

going into too much detail about each component of the executive compensation, we can broadly represent the compensation (V_i) of individual manager i as consisting of a fixed part (f_i) and a bonus (b_i) linked to performance:

$$V_i = f_i + b_i \tag{2.1}$$

We distinguish between two types of performance evaluations used to determine the manager's bonus, namely the relative performance evaluation (b^{RPE}) and the absolute performance evaluation (b^{APE}).

We make two simplifying assumptions to show how these bonus systems affect managerial decisions. First, we only look at two firms competing in a market[3]. Second, we assume that the primary metric for performance evaluation is based solely on companies' profits[4], similar to theoretical approach by Vickers (1985) and Jansen et al. (2008) and empirical approach by Aggarwal and Samwick (1999a). While the APE-based bonus focuses exclusively on the profits of the firm for which the manager works (Π_i), the RPE-based bonus also considers the profits of the competing firm j (Π_j). The APE and RPE-based bonuses are given by:

Absolute profit evaluation (APE): $$b^{APE} = \omega_i \Pi_i \tag{2.2}$$

Relative profit evaluation (RPE): $$b^{RPE} = \alpha_i \Pi_i - \gamma_i \Pi_j \tag{2.3}$$

where $\alpha_i > 0$ and $\omega_i > 0$ are the weights, the owner of the firm i assigns to its own profit and $\gamma_i > 0$ to the profit of the competitor j.

To examine the impact of RPE and APE on quantity choice, we consider a standard quantity-setting duopoly where the inverse demand is given by:

$$P(q_i, q_j) = a - q_i - q_j,$$

where $a > 0$, p is price, and q_i is firm i's output. Firms have symmetric costs given by $C(q_i) = cq_i$. Hence, firm i's profit is given by:

$$\Pi_i = (a - q_i - q_j)q_i - cq_i$$

Assuming that the manager's goal is to maximise their own compensation (V_i), APE- and RPE-based compensation systems lead to the following two manager response functions:

$$q_i^{*APE}(q_j) = \frac{a-c}{2} - \frac{q_j}{2} \tag{2.4}$$

[3]For interested readers, Jansen et al. (2008) provides a similar analysis for triopolies.

[4]There are, of course, other metrics, including sales, market share, revenue, and relative shareholder return. Looking at all of them would be beyond the scope of this chapter.

$$q_i^{*RPE}(q_j) = \frac{a-c}{2} - (1 - \frac{\gamma_i}{\alpha_i})\frac{q_j}{2} \quad (2.5)$$

As is evident from Equation 2.2, as long as the weight ω_i is positive, the payoff-maximising manager would choose quantities that also maximise the firm's profits. In other words, even a small weight ω_i is sufficient to ensure a complete alignment between the incentives of the owner and the manager. The response function of the manager is then given by equation 2.4 and is equivalent to the best response function of profit-maximising firm i (owner).

In contrast, the RPE-based contract leads to a manager's response function that deviates from the best response function of the profit-maximising owner. Both α_i and γ_i parameters affect the manager's best response function. Figure 2.1 illustrates the resulting differences in the response functions under the RPE and APE compensation schemes. The manager's response function under the RPE contract is downward sloping if both parameters are positive and if α_i exceeds γ_i ($\alpha_i > \gamma_i > 0$). However, the response curve associated with RPE is flatter, suggesting that the manager will choose quantities that exceed profit-maximising quantities as long as the competitor produces at least one unit of output. For larger quantities of the competitor, the deviation increases in absolute terms[5]. Therefore, we would expect compensation-maximising managers to choose larger quantities in the case of RPE-based compensation than in the case of APE-based compensation, leading to our first hypothesis[6].

Hypothesis 1 (H1) *Managers' strategies under RPE-based compensation will contain higher output quantities than managers' strategies under APE-based compensation.*

Our first hypothesis assumes that managers maximise their compensation; however, it is also possible that managers deviate from this behaviour as they optimise their own (unknown) objective functions. Armstrong and Green (2007), for example, provide empirical evidence that managers' mere knowledge of rivals' profits is sufficient to trigger aggressive behaviour, and the results of a laboratory study reported by Armstrong and Collopy (1996) suggest that subjects were willing to sacrifice a portion of their firm's

[5]However, if the owner weights the profit of his firm i and the profit of the competitor equally ($\alpha_i = \gamma_i$), the manager would always choose the monopoly output. If the owner puts an even larger weight on the competitor's profit, the slope of the response curve can be positive. Since it is unreasonable to believe firm owners choose weights in this manner, one can assume that the competitor's profit is less important than the company's own profit ($\alpha_i > \gamma_i > 0$).

[6]Because our focus is on the effects of RPE- and APE-based compensation schemes on managers' output decisions, we do not address why firm owners might use RPE-based compensation schemes. However, according to the strategic delegation literature, firms may use RPE to create incentives for managers to make more aggressive decisions to put competitors in a disadvantageous position (Vickers, 1985; Sklivas, 1987; Jansen et al., 2008). Another reason owners might use RPE-based compensation systems relates to a firm's internal perspective and is based on the "informativeness principle" (Holmstrom, 1979), according to which RPE-based compensation can be used to solve problems related to asymmetric information between managers and owners. In this regard, the adverse effects of RPE systems on profits could be an unintended side effect rather than a conscious decision by owners.

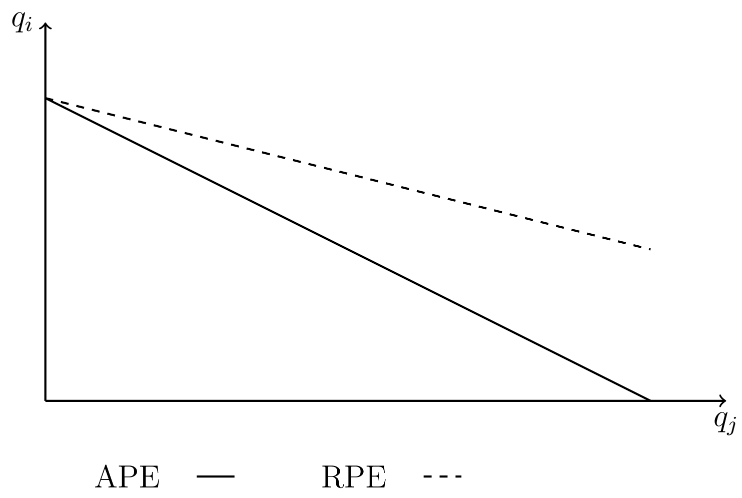


Figure 2.1: Manager's Optimal Response Functions under APE- and RPE-based Compensation Schemes

profits to beat or harm the competitor when information about the competitor's profits was available. Griffith and Rust (1997) find that subjects in a prisoner's dilemma pricing experiment tended to base their decisions on a comparison with rivals, even though they were explicitly instructed and had the incentive to maximise their own firm's profits.

The theoretical contribution by Miller and Pazgal (2002) explicitly considers that managers may have different objective functions. They show that profit-maximising firm owners may exploit managers' personality traits to force the competitor into a less profitable position. The authors consider two-stage games where profit-maximising owners select managers with certain attitudes towards relative performance in the first stage; these managers then compete in a duopoly in the second stage. Miller and Pazgal (2002) argue that there are different types of managers, which differ in the objective function they optimise, i.e., how they weigh the profits of their own company compared to the profits of their competitors. The aggressive type of manager places more emphasis on the difference between their own company's profits and their competitors' profits. In contrast, highly cooperative managers may even give positive weight to the profits of their competitors. Thus, in the theoretical model developed by Miller and Pazgal, business owners do not commit to a particular compensation scheme to change managers' response function; instead, managerial types act as strategic commitment devices that can increase firm profits.

The model developed by Miller and Pazgal highlights a crucial point: managers can differ in their aggressiveness, leading them to make decisions that deviate from profit-maximising behaviour. Despite recognising the existence of diverse types of managers, the study by Miller and Pazgal (2002) does not investigate the potential interactions between the objective functions of managers and various performance-based compensation schemes. Managers may behave aggressively in APE-based compensation systems, and an aggressive manager may choose a higher than the profit-maximising production level on his or her initiative. Arguably, aggressive behaviour would at least persist under an RPE-based compensation system, but RPE-based compensation could also provide an incentive for even more aggressive behaviour[7]. In our framework, the RPE contract already assumes an elevated level of production quantities; thus, we use the compensation-maximising quantities as our benchmark for *over*-aggressive behaviour. Accordingly, we define any choice above contractually optimal quantity as *over*-aggressive, as managers sacrifice their remuneration to damage the profits of the competitor. We expect RPE-based compensation to act as a signal for a manager to engage in such behaviour. This leads to our second hypothesis:

Hypothesis 2 (H2) *The likelihood that managers will act over-aggressively is higher in an RPE-based compensation system than in an APE-based one.*

Managers' choice to overproduce under RPE-based contracts should be particularly concerning for firm owners. On the one hand, any deviation from profit-maximising behaviour is already detrimental to the firm. On the other hand, due to the quadratic nature of profits, deviations above the benchmark level of the RPE contracts are even more costly, as RPE-based compensation already assumes higher quantities. For this reason, we concentrate specifically on over-aggressive behaviour.

Hypothesis 2 relies on the assumption introduced by Miller and Pazgal (2002) and explicitly assumes that the negative weight managers place on the competitors' profit is constant along the response curve. However, the tendency to engage in over-aggressive behaviour may also depend on whether the manager's firm is in a favourable or unfavourable position relative to the competitor firm. Indeed, findings from behavioural economics research suggest that envy can be triggered when one receives fewer resources than a competitor, leading to spiteful behaviour (Wobker, 2014). Fehr and Gächter (1998) note that individual behaviour can be driven by behindness aversion (aversion to negative payoff inequality). Therefore, managers whose firms are in a disadvantageous position might use any means to reduce or compensate for that disadvantage. This practice is also known as "beating someone at any cost"(Malhotra et al., 2008; Graf-Vlachy, 2021). In the RPE-based compensation system, some of these costs are already internalised, making it easier to "beat" the competitor (or at least achieve a more favourable relative position) than in an APE-based compensation scheme. Against this background, we expect that RPE-based compensation schemes would intensify spiteful behaviour further

[7]It is less clear how highly cooperative managers might react to the introduction of an RPE-based compensation scheme. On the one hand, managers who choose lower than the compensation-maximising quantities under the APE-based compensation system may choose higher output levels under RPE-based compensation because cooperative behaviour has a more detrimental effect on their compensation. On the other hand, cooperative managers may be willing to sacrifice their own compensation to behave cooperatively.

than APE-based compensation schemes. In other words, the RPE contracts moderate the effect of being in a disadvantageous position. Based on these considerations, we formulate a two-part Hypothesis 3:

Hypothesis 3a (H3a) *Managers are more likely to exhibit over-aggressive behaviour when the manager's firm is in a disadvantageous position.*

Hypothesis 3b (H3b) *The RPE compensation scheme has a positive effect on the likelihood of over-aggressive behaviour by a manager, particularly if the manager's firm is in an unfavourable position.*

2.3 Experimental Design

Testing Hypotheses 1-3 requires individual response functions, which is problematic under the simultaneous move framework. For this reason, we use Stackelberg (1934) model, which features sequential decision-making[8] in a quantity-setting environment. Furthermore, we opt for the strategy method (Brandts and Charness, 2011), where we ask the participants to create response plans for possible choices of the leader. This approach has clear advantages over using repeated sequential interactions. In the latter, we would only observe follower behaviour for a subset of the leader choices, leading to identification and categorisation issues (Müller and Tan, 2011).

Thus, we can summarise the experiment in the following way. After participants become familiar with the market environment, they are randomly assigned to either the APE or RPE compensation scheme and create a response plan for different leader choices (between-subject design). In the next step, each participant also creates a response plan for the bonus system to which the participant was not assigned in the first round (within-subject design). These measurements produce two response functions for each subject (which are the main objective of our design). Then, participants submit two quantities as the leader firm (against each type of contract of the follower). After the decision-making phases are completed, the participants are brought together. The roles (leader or follower in the Stackelberg setting) and type of contract of the followers (APE or RPE) are chosen randomly. Then one participant's response plan is matched against the leader quantity of the other, and both participants receive their respective payoff.

The rest of this Section provides explicit details about the experimental market environment (Section 2.3.1), instructions and materials (Section 2.3.2) and sample information (Section 2.3.3).

2.3.1 Experimental Market

First, we summarise the specific market environment based on the framework outlined in Section 2.2. For our experiment, we have used $a = 80, c = 0$ and $f = 100$ as values

[8]For the comparison between Stackelberg and Cournot games, see Huck et al. (2001).

for our parameters, and $\omega = 1, \alpha = 1.33$ and $\gamma = 0.33$ as the weights for compensation decisions. The market is characterised by Stackelberg competition, where the leader firm moves first, and then the follower firm moves second.

The inverse demand function is given by:

$$P(q_l, q_f) = 80 - q_l - q_f$$

where the subscript l represents the leader and f the follower. The profits of both firms are given by

$$\pi_i = (80 - q_i - q_j) * q_i, \;\; i{=}l{,}f$$

In both firms, only the manager decides on the quantity. The firm l chooses the quantity first, and firm f replies using a pre-constructed response plan. In the case of a bonus scheme based on the APE, it depends exclusively on the profits of the follower firm:

$$v_f^{ape} = \begin{cases} \pi_f + 100 & \pi_f > 0 \\ 0 & \text{otherwise} \end{cases} \tag{2.6}$$

In the case of the RPE bonus scheme, the reward of the manager of the follower firm depends on the profits of both firms:

$$v_f^{rpe} = \begin{cases} \pi_f + 100 + 0.33 * (\pi_f - \pi_l) & v_f^{rpe} > 0 \\ 0 & \text{otherwise} \end{cases} \tag{2.7}$$

The subgame-perfect equilibrium suggests that for each possible level of output q_l of the leader, the follower would respond by maximising $v_f^{ape}(q_l)$ or $v_f^{rpe}(q_l)$. Therefore, the best-response functions for follower for the two bonus schemes are

$$q_f^{ape}(q_l) = 40 - 0.5\, q_l \tag{2.8}$$

$$q_f^{rpe}(q_l) = 40 - 0.376\, q_l \tag{2.9}$$

Creating a best-response plan for every possible leader choice is not feasible in the context of our experiment. Therefore, we restrict the possible action domain of the leader to a discretised set of the Stackelberg game with $q_l \in \{1, 7, 14, 20, 27, 33, 40, 48, 56\}$. The action space of the follower firm (q_f) is only restricted to integers in the range $[0, 80]$. The manager of the leader firm will receive compensation based on the APE contract. Since the manager of the leader firm knows what type of compensation the manager of the follower firm will receive, it is optimal in terms of maximising his own compensation to commit to a quantity of 40 if the manager of the follower firm is paid under the APE contract and 33 if it is under the RPE contract[9].

2.3.2 Materials and Procedures

The instructions have presented the above market conditions to the participants using non-neutral language, for example, referring to "firms," "managers," "products," and "profits". This approach is favoured in the experimental IO literature[10] and is supported by methodological surveys (Alekseev et al., 2017). The introduction page also included a description of a profit calculator that showed profits resulting from any given combination of the quantities. The use of the profit calculator is not a novel idea[11], but since the strategy space of the experiment is relatively large, we have modified the profit calculator with "sliders" that show profits in real-time. Thus, instead of manually typing the number each time, participants could change the slider's position and see the immediate change in the payoffs both for themselves and their opponents (See Appendix 2.D for an example and complete instructions). This calculator was available to participants throughout the entire experiment.

To ensure that participants understood the environment and how the sliders work, they were given three control questions about possible situations under the described market conditions. These questions could only be answered using a calculator and were the same for all participants. Participants were only allowed to proceed if they answered all questions correctly.

After the introduction to the environment, participants received information about the decision stages, which included details about payments and matching procedures. The experiment used an experimental point (EP) as a currency with an exchange rate of 100 EP=1 GBP (British Pound).

Throughout the decision stages, participants were asked to first assume the role of manager of firm B (the follower firm) and then firm A (the leader firm). Completing the stages as firm B's manager required subjects to submit a "response plan" for every possible node in the strategy space of the leader. The starting condition (either APE or RPE) was chosen randomly to control for potential order effects.

After the participants completed the response plans of followers for both types of contracts, they made two decisions as managers of firm A. Even though the main objective of the design is to elicit the response functions of the follower, collecting the choices for the leaders shows whether participants anticipate the strategies of the followers and adjust their choices accordingly. Since the leader's choice is made after completing follower decision stages and there is no control for order effects, these data points are not a

[9] The exact best response is $\frac{2660}{83} \approx 32$, but due to discretised action set, the closest is 33.

[10] For examples, see Müller and Tan (2011), or Du et al. (2013).

[11] For example, Du et al. (2013) also use a calculator, and Requate and Waichman (2011) demonstrate that experimental results in duopoly market games are not significantly different between payoff calculator and payoff table.

reliable metric.

By the end of the experiment, each participant submitted 20 data points: 9 for each type of contract as the manager of a follower firm and 2 decisions as the manager of a leader firm against two types of contracts.

2.3.3 Experimental Sample

To test our hypotheses, we employ a lab-in-the-field experiment conducted online in 6 sessions between September 2021 and January 2022. The participants were recruited via Prolific.ac (Palan and Schitter, 2018), and the interface has been programmed using LIONESS platform (Giamattei et al., 2020), along with standard tools for website design (HTML, CSS and JavaScript). To minimise cultural differences between participants, we have restricted the experiment to participants from the United Kingdom, the US and Ireland. A total of 330 people participated in the experiment. However, due to strict data quality policy, this number has been reduced to 197[12]. Although online experiments are now relatively widespread and accepted in experimental economics and were almost inevitable under COVID-19 constraints, they also present some challenges from a methodological perspective. In Appendix 2.B, we briefly describe these challenges and explore their implications for our experimental design.

On average, participants completed the experiment in 25 minutes and received an amount of £7, depending on the decisions made in the experiment, and £2.2 as participation compensation. Column 1 in Table 2.A.1 provides complete demographic information about our sample (see Appendix 2.A).

2.4 Experimental Results

We illustrate our main results with Figure 2.2, which shows the average observed response plans for the two treatments, i.e., the APE and the RPE-based compensation schemes. The 95 % confidence intervals for the means are also reported. The linear response curves (dashed lines) derived under the assumption of compensation maximisation serve as reference points for both compensation schemes. This graph highlights three initial findings. First, observed quantities are higher when subjects make their decisions under the RPE-based compensation scheme than under the APE-based compensation scheme, particularly for larger quantities of the leader, providing prima facie support for Hypothesis 1. Second, the average quantities chosen by the subjects in both compensation schemes tend to deviate from the compensation-maximising amounts. These deviations are particularly significant for large and small quantities of the competitor. Third, the observed average response plans show flatter response curves than the respective theoretically predicted linear “optimal” response curves derived under the assumption of compensation maximisation.

[12] 63 subjects have not completed the experiment, 67 subjects have failed the attention checks, and three subjects made choices outside the allowed strategy space.

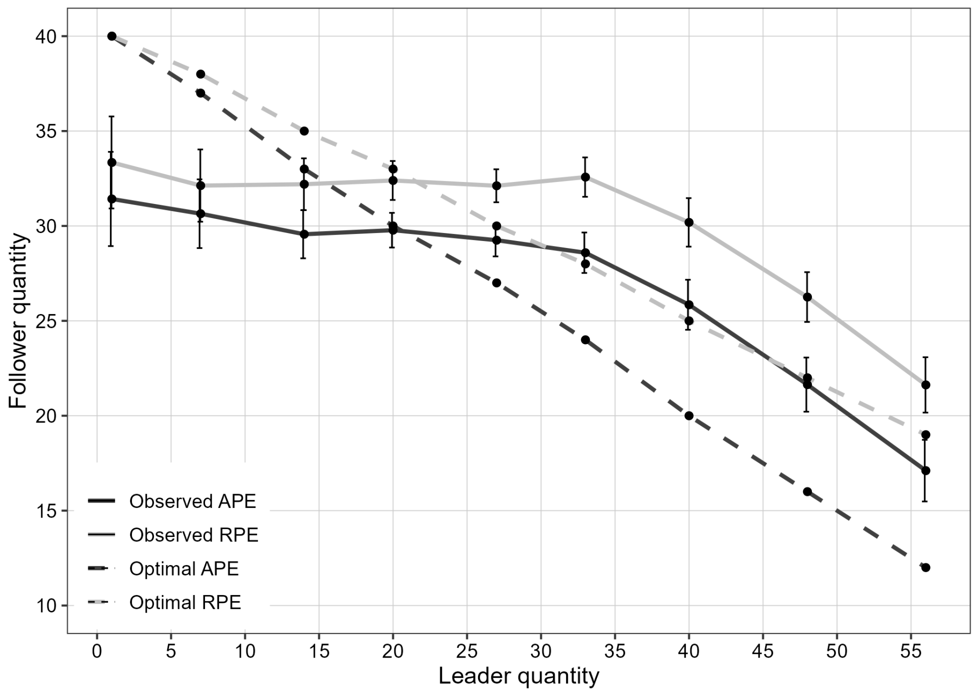


Figure 2.2: Optimal and Observed Average Response Functions

Furthermore, the observed response curves intersect the theoretical response curves, suggesting that subjects opt for higher-than-optimal production levels when the competitor chooses larger quantities. In contrast, the observed production quantities are below the "optimal" levels when the competitor's quantities are low. These observations provide initial empirical support for our Hypotheses 2 and 3. We now turn to more formal statistical tests of our hypotheses.

Hypothesis 1

Although Figure 2.2 already provides compelling evidence in favour of Hypothesis 1, for the sake of completeness, we also provide results of a regression analysis. Based on individual response plans and the corresponding competitor (leader) quantities, we estimate the causal effect of the RPE treatment on the quantities chosen by the follower. To this end, we employ the following econometric model:

$$Q_{fji} = \alpha_0 + \alpha_1 Q_{lj} + \alpha_2 (Q_{lj} \times RPE_{ji}) + u_{ji}$$

where Q_{fji} are the *observed* quantities chosen by subject i (i=1,...n) in response to the leader quantity Q_{lj}, where j represents the nine quantities of the leader (j=1,...,9) for which the subjects made their response plan. RPE represents a dummy variable that takes the value one if the choice is made under the RPE compensation scheme and is zero otherwise. The error term is u_{ji}. The second term is the interaction between leader quantity and RPE, i.e., the treatment. Our theoretical considerations suggest that the sign of the estimated value of parameter α_1 is negative, implying a downward-sloping best-response curve, and according to Hypothesis 1, the sign of the estimated value of parameter α_2 is positive.

Table 2.1: Estimated Linear Response Functions of Followers

	Model 1	Model 2	Model 3
Intercept	34.235***	34.235***	33.443***
	(0.947)	(0.947)	(1.014)
Q_l	−0.202***	−0.253***	−0.232***
	(0.029)	(0.031)	(0.032)
$RPE \times Q_l$		0.101***	0.060**
		(0.010)	(0.021)
RPE			1.585*
			(0.771)
Num.Obs.	3546	3546	3546
R2	0.096	0.117	0.118

Notes: Significance levels at *p < 0.05, **p < 0.01, ***p < 0.001. Cluster-robust standard errors are in parentheses.

Table 2.1 reports coefficients obtained from OLS regressions and robust errors clustered at the individual level[13]. To set the scene, we first present the results of a regression where we assume that the contract based on RPE does not affect subjects' response plans differently than the contract based on APE (Model 1). As theoretically expected, the estimated value of parameter α_1 is negative, implying that the average response curve is downward-sloping. Moreover, the estimated coefficient is statistically significant at the one per cent level. Next, we allow for differences in the effects of APE- and RPE-based compensation schemes on subjects' response plans. As hypothesised, the coefficient α_1 is negative in Model 2, implying that the average response function is downward-sloping for the APE contract. The estimate of parameter α_2 is positive and statistically significant at the one per cent level, indicating that the RPE environment results in relatively higher quantities than APE contracts, i.e. the causal effect of RPE is positive. According to our theoretical considerations (Eq. 2.8 and 2.9), the RPE contract should only affect the slope of the best response curve and not shift it. Nevertheless, we also run a model that allows for a change in intercept (Model 3). In the latter case, the total causal effect of the treatment RPE on the subjects' response plans is given by the main effect of RPE plus the interaction with leader quantity $(1.585 + 0.060Q_{lj})$. While the main effect of the RPE contract, i.e., the estimated value of the parameter of the RPE dummy variable, is positive, it is only statistically significant at the five per cent level. The estimated effect of the interaction term is still positive, although the estimated value is somewhat lower.

[13]We employ cluster-robust standard errors to account for autocorrelation induced by multi-level data. Although there are some arguments in favour of using linear mixed-effects models due to the nested structure of the data (9 observations per contract per participant), the number of clusters is sufficient to have a consistent estimate for the standard errors. See Oshchepkov and Shirokanova (2020) for a discussion.

Thus, despite the observed response functions being different from theoretical predictions, our results strongly support Hypothesis 1.

Hypotheses 2-3

While the above approach is a straightforward way to verify whether the RPE environment elicits higher quantities, it fails to consider the implied differences in compensation-maximising (optimal) behaviour under each contract. Accordingly, even if the choices under RPE are higher than under APE, it does not mean that participants are overly aggressive towards their opponent (as is the case for low quantities of the leader in Figure 2.2). Thus, to illustrate these different strategies, we introduce Figure 2.3, which presents the distribution of each type of behaviour for every possible output of the leader. We categorise "over-aggressive behaviour" ("above optimal") as any choice Q_{fji} which exceeds the payoff-maximising quantity for the respective choice of the leader firm (Q_{lj}) by more than 1 unit (to allow for the discretisation of payoffs), "optimal" as any choice within 1 unit interval above or below payoff-maximising quantity, and "below optimal" otherwise. Two patterns emerge. First, overly aggressive behaviour seems to be more frequent *in general* under the RPE compensation scheme supporting our Hypothesis 2. Second, under both contracts, subjects exhibit a greater tendency for over-aggressive behaviour ("above optimal") when the leader puts them in a disadvantageous position, supporting our Hypothesis 3a. However, the potentially moderating effect of the RPE compensation scheme, suggested by Hypothesis 3b, is less clear.

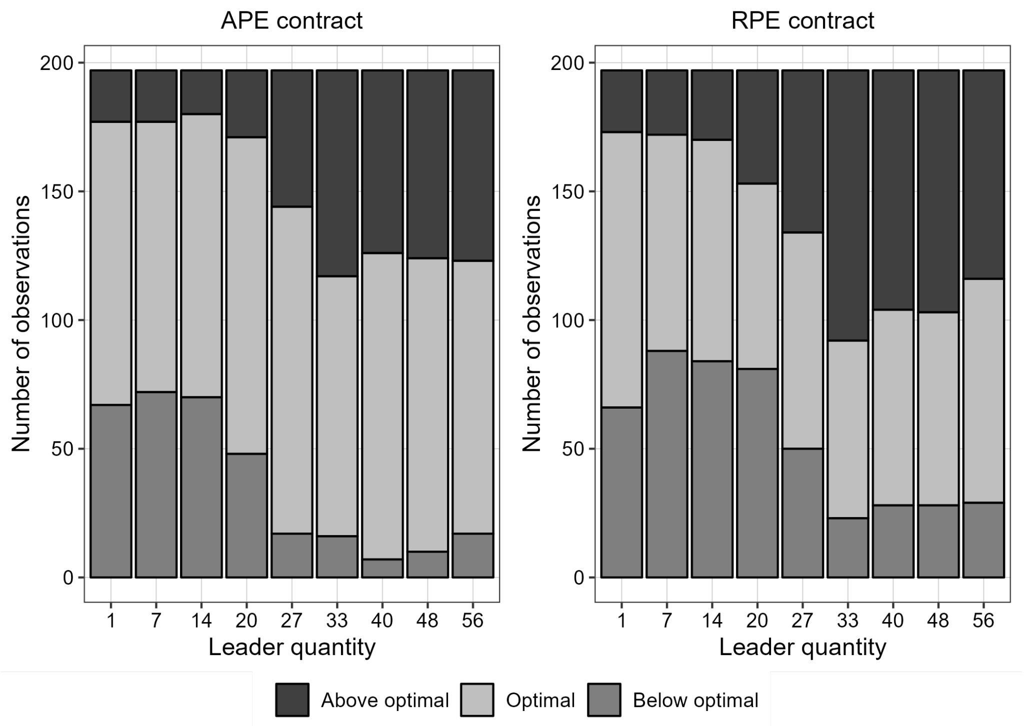


Figure 2.3: Observed Behaviour for Different Leader Quantities

For the statistical tests of Hypotheses 2-3, we analyse the probability of observing over-aggressive behaviour. Formally, Y_{ji} is a binary variable that takes the value one if a participant i's response to a leader quantity j is over-aggressive ("above optimal") and is zero otherwise. We use the following econometric specification of a logistic model for our regression analysis:

$$ln\frac{P(Y_{ji}=1)}{1-P(Y_{ji}=1)} = \beta_0 + \beta_1 RPE_{ji} + \beta_3 Behind_j + \beta_4 Behind_j \times RPE_{ji} + \eta_{0i}$$

where $P(Y_{ji} = 1)$ is the probability that participant i's response is over-aggressive ($Y_{ji} = 1$), RPE is the dummy to represent the RPE contract, and $Behind_j$ is a dichotomous variable taking the value one if the leader quantity j is above the threshold for a disadvantageous position. Our approach in establishing this threshold is similar to Lau and Leung (2010). Intuitively, if the optimal choice of the follower in response to leader quantity j results in a higher payoff for the follower, then the follower is in an advantageous position. Thus, $Behind_j$ takes the value zero for all responses to leader choices j below 27 (33) for the APE (RPE) compensation scheme and is one otherwise. We accommodate the panel structure of our data by including a random intercept (η_{0i}) in our analysis (Gelman and Hill, 2006, 301). Logistic regressions were run in R with lme4 package(Bates et al., 2015).

We report the results of the above analysis along with two reduced-form logistic regressions in Table 2.2 along with simple linear probability models[14] (Table 2.2: LPM 1-3) for the convenience of the reader. The coefficients obtained from the linear probability models reflect the marginal effects on the probability of the occurrence of over-aggressive behaviour and are therefore useful to illustrate the marginal effects, although strictly speaking, they are not entirely correct (see Beck (2019)).

The coefficient estimate of β_1 is positive and statistically significant at the 0.1 per cent level ($p<0.001$) in all of our logit models (RE Logit 1-3), indicating the RPE contract increases the log-odds ratio of observing quantities above payoff-maximising values. Thus, we can infer that the RPE environment increases the tendency to engage in overly aggressive behaviour, providing strong support for Hypothesis 2. The coefficient estimate of β_2 is also positive and statistically significant ($p<0.001$), implying that being in a disadvantageous position encourages over-aggressive behaviour under both contracts (Hyp. 3a). The coefficient for the interaction term is not statistically significant at conventional significance levels (RE Logit 3). In fact, omitting the interaction term improves most model specifications we estimate, suggesting that we cannot confirm Hypothesis 3b that RPE environment has a stronger effect on the likelihood of over-aggressive behaviour if a

[14]Throughout the chapter, linear probability models are estimated with OLS regression. Reported errors are cluster-robust. See Pustejovsky and Tipton (2017) for methodology.

Table 2.2: Determinants of the Probability of Over-aggressive Behaviour: Logistic Regressions and Linear Probability Models

	RE Logit 1	LPM 1	RE Logit 2	LPM 2	RE Logit 3	LPM 3
RPE	0.478***	0.069***	0.845***	0.099***	0.893***	0.080***
	(0.087)	(0.020)	(0.100)	(0.020)	(0.163)	(0.020)
Behind			2.194***	0.269***	2.238***	0.251***
			(0.111)	(0.026)	(0.161)	(0.028)
RPE × *Behind*					−0.078	0.037
					(0.205)	(0.028)
Intercept	−1.728***	0.245***	−3.318***	0.095***	−3.347***	0.105***
	(0.145)	(0.020)	(0.195)	(0.019)	(0.211)	(0.017)
Num.Obs.	3546	3546	3546	3546	3546	3546
AIC	3491.7	4363.1	3015.8	4032.6	3017.7	4033.0
BIC	3510.3	4381.6	3040.5	4057.3	3048.5	4063.9

Notes: Significance levels at *p < 0.05, **p < 0.01, ***p < 0.001.
Logistic regressions (RE Logit 1-3): Coefficients are in log-odds for intercept and log-odds ratios for predictors. Linear Probability models (LPM 1-3): Dependent variable $Pr(Y_{ij} = 1)$. Coefficients are in the marginal probabilities. Cluster-robust standard errors (for LPMs) are in parentheses.

participant is in an unfavourable position. These results are confirmed by the estimates obtained from the linear probability models. Furthermore, the estimated marginal effects show that RPE contracts increase the likelihood of observing over-aggressive behaviour by almost ten percentage points. The marginal effect of an unfavourable position is even stronger, leading to an increase in the probability of over-aggressive behaviour by more than 25 percentage points.

Robustness Checks

As with any experiment, it is inevitable to make certain decisions regarding the experimental design and the type of empirical analysis of the data. Therefore, to check the robustness of our results, we perform some additional analyses. The results of these additional analyses are presented in Appendix 2.C. Because we used a within-subjects design in which subjects had to make decisions related to both APE-based compensation and RPE-based compensation, it could matter whether they received one form of compensation first and then the other, or vice versa. In other words, there may be concerns about potential order effects. For example, Huck and Wallace (2002) provide some evidence of aspiration effects: once subjects have experienced symmetric payoffs, they are not easily forced into an unfavourable position. These aspiration effects could affect the participants who start with the APE condition. We address this issue in two ways. First, we run our previous analyses while controlling for order effects. The resulting tables 2.C.1-2.C.3 show that the order variable is not statistically significant and does not improve the fit of either of our models.

Second, we run the same analyses only for the sub-sample of observations with the first exposure to either APE or RPE (i.e. employing a strict between-subject comparison). While we lose some statistical power due to fewer observations, we still observe a significantly higher tendency to engage in overly aggressive behaviour under the RPE contract (Appendix 2.C - Table 2.C.4).

Furthermore, in our tests for Hypotheses 2-3, we account for the nested structure of the data by only incorporating random intercepts in our models. Including subject-specific random effects in a model is generally recommended for the inferences about individual responses (Lee and Nelder, 2004), which is our primary research objective. As an additional robustness check, we also run generalised linear mixed models (see Rabe-Hesketh et al. (2000)) with random slopes for contracts and "behindness" on individual level[15]. While these model specifications do not change the significance or quality of the above conclusions, they slightly increase the magnitude of the predicted effect of the RPE environment. We present the results in Table 2.C.5 as part of the Appendix 2.C.

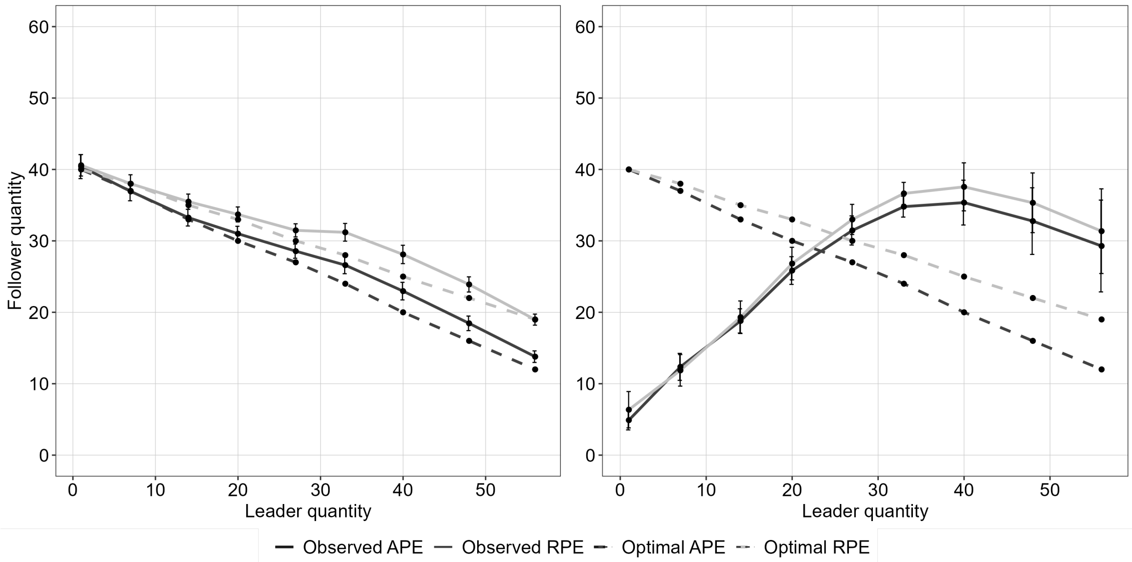


Figure 2.4: Observed Average Responses for Groups of Subjects with Positively and Negatively Sloped Response Curves

Finally, we consider the heterogeneity in our data in terms of the slope of the individual response curves, which we can identify by the strategy method. To this end, we estimate individual linear response functions. Based on our estimates of the α_{i1} parameter for each subject, we are able to identify three groups of participants. Consistent with our theoretical considerations, we find negatively sloped response curves for 141 participants. However, there are also 39 participants with positively sloped response curves and for 17 participants we find a random pattern (see Appendix 2.A, Table 3.A.1 for the demographic details of each group).

Figure 2.4 shows the average individual response curve estimates for the groups of

[15]Following the advice by Sommet and Morselli (2017).

participants with negatively and positively sloped best-response curves. Not surprisingly, the chosen quantities are considerably closer to the theoretical predictions for the group of participants with negatively sloped response curves than for the other group. However, even for these 141 participants, our estimates show that RPE compensation increases the probability that subjects act over-aggressively (see Table 2.C.6, Appendix 2.C). This robustness check provides additional empirical support for Hypothesis 2. Moreover, the estimated coefficient of the interaction term is now statistically significant ($p<0.01$). Thus, for this group of subjects, we find empirical evidence that the RPE reward system has a stronger positive effect on the probability of over-aggressive behaviour when the subject's company is in an unfavourable position (Hyp. 3b).

Our estimates suggest that 20 per cent of subjects have a positively sloped best response curve, which could be explained by a strong preference for fairness in this group of subjects. Choosing the same quantity as the Stackelberg leader in their response plans ensures that, with APE compensation, both the leader and the follower receive the same payoffs[16]. This explanation is also supported by the fact that we find little difference between the average response curves for APE and RPE contracts in this group.

2.5 Discussion

In this study, we conduct an online lab-in-the-field experiment to investigate how managerial behaviour is affected by RPE-based compensation compared to APE-based compensation. More specifically, we examine the causal effect of the RPE compensation scheme on followers' strategies in a Stackelberg duopoly market. The results of our experiment confirm our first hypothesis that managers' responses under the RPE environment contain higher output quantities than under the APE environment. In other words, subjects in our experiment make more "aggressive" quantity choices under the RPE contract. While our study focuses exclusively on the managers' perspective and not on business owners' decisions regarding the nature of managerial compensation systems according to the literature on strategic delegation, more aggressive managerial behaviour induced by the RPE environment is the primary justification for the use of competitor-oriented incentives (Vickers, 1985; Salas Fumas, 1992).

However, our results suggest that the average response curves for both APE- and RPE-based contracts are significantly flatter than predicted under the compensation maximisation assumption. This observation suggests that participants in our experiment tend to maximise individual (unknown) objective functions. Previous studies of experimental markets (e.g., Müller and Tan (2011); Huck and Wallace (2002)) have reported similar findings for APE-type contracts (i.e. the incentives tied only to the own profit of the

[16]Initially, we have assumed that choosing the same quantity could be the least mentally taxing strategy for participants. Although this conjecture may still be true for some subjects, several participants voluntarily messaged us to describe their strategy as *specifically* based on fairness.

company). Our results show that this is also the case for RPE-type contracts.

Our results also confirm our second hypothesis. While we find significant deviations from compensation maximisation in both APE and RPE contracts, our results suggest that RPE-based compensation, in particular, encourages over-aggressive behaviour, as we observe an increased tendency to sacrifice one's own compensation in order to impair the performance of the competing firm.

Finally, our third hypothesis, that managers are more willing to engage in over-aggressive behaviour when the manager's firm is in a disadvantageous position and that an RPE-based compensation system amplifies this effect, is only partially confirmed by our data. We find that participants are more willing to choose a high output level and thus sacrifice their compensation when their firm's profits are lower than those of the competing firm. This behaviour could be explained by participants' behindness aversion. Similar conclusions are presented by Müller and Tan (2011) and Cardella and Chiu (2012), who show the presence of spiteful behaviour under the APE setting both for individuals and groups. However, in contrast to previous studies, our results show that this behaviour persists under the RPE system, and, furthermore, our results can be interpreted as causal effects. The second part of our third hypothesis, that the strength of this effect depends on the type of compensation system, is only partially confirmed. While we do not find a statistically significant interaction effect in the overall sample, we do find empirical evidence for our hypothesis in the group of subjects with negatively sloped response curves (72 per cent of subjects), confirming that RPE increases the likelihood of over-aggressive behaviour, at least in this group.

In summary, our results suggest that RPE-based compensation influences subjects' decisions in a way that leads to very aggressive quantity decisions. This behaviour has a significant negative impact on firm profits and the subjects' compensation. Although our experiment focuses on identifying the causal effects of RPE- vs APE-based compensation schemes on managerial decision-making, our results also contribute to the literature on strategic delegation (Vickers, 1985; Jansen et al., 2008) and the literature on the effects of competitor-oriented objectives on firm performance (Armstrong and Collopy, 1996; Armstrong and Green, 2007; Griffith and Rust, 1997). According to our results, using RPE-based compensation systems as a strategic commitment device could backfire because aggressive managers could choose extreme output levels that reduce their firm's profits beyond what owners might expect. Aggressive managers may even perceive RPE-based compensation systems as a signal from the owner that their aggressive behaviour is desirable. In this case, business owners would essentially be adding fuel to the fire. Our results may thus explain the observation that competitor-oriented objectives are associated with reduced profitability of firms (Armstrong and Green, 2007).

While our study has links to previous experimental studies in the field of strategic delegation, it differs from those studies in two respects. First, we investigate the impact of an RPE-based compensation scheme. Previous studies examined other remuneration schemes, such as a sales bonus in a Cournot duopoly (Huck et al., 2004a) or a revenue bonus in a mixed duopoly (Du et al., 2013). Second, we also use a different experimental design. We focus on the effects of compensation systems on managers' decisions, whereas previous studies on strategic delegation focused on firm owners' decisions. Methodologically, this means that our results can be interpreted causally since the assignment of the subjects to the two compensation systems is exogenous (randomised). In contrast, in previous studies, subjects (firm owners) determined the compensation system for other subjects (managers). As the choice of compensation schemes is endogenous, the effects on managerial behaviour observed in these studies cannot be interpreted causally.

Moreover, our study also contributes to the literature dealing with the link between executive compensation based on RPE and incentives to engage in costly sabotage (Harbring and Irlenbusch (2011); Harbring et al. (2007)). While most of this literature addresses RPE and sabotage within firms, RPE-based compensation systems can also incentivise costly sabotage against other firms. For example, Bloomfield et al. (2023)[p.2] note that "in the context of CEO compensation, costly sabotage would likely take the form of overly aggressive product market strategies, such as sub-optimally low prices, extreme output volumes, or excessive advertising spending". The authors argue that such actions harm the value of companies making use of RPE-based compensation schemes and may explain the "RPE puzzle," i.e., the reluctance of firm owners to use RPE as a basis for CEO compensation. By using firm-level data, Bloomfield et al. (2023) provide quasi-experimental evidence for a causal influence of cartel membership on the likelihood of using RPE in CEO compensation, particularly in concentrated markets. Their findings present some indirect evidence for a relationship between RPE and inter-firm sabotage as "cartel membership substantially diminishes the potential for RPE to induce costly sabotage, thereby enhancing the net benefits of its use"(Bloomfield et al., 2023, p.2)[17]. However, these results do not provide direct evidence of a causal effect of RPE-based compensation schemes on managerial decision-making, as firm-level data do not allow for an investigation of such effects. In contrast, our experimental framework allows us to identify the causal effect of compensation schemes on individual management decisions. Furthermore, unlike field firm-level data, in our experiment, all relevant data are perfectly observable, making it easier to detect cases of costly sabotage, i.e., whether subjects make decisions that harm not only their competitors but also their own firm's profits and their own remuneration.

Our findings are also relevant to practitioners because they point to unintended side effects of RPE-based compensation systems. Our results suggest that RPE-based compensation systems may affect managerial behaviour in ways not intended by those who

[17]Further indirect evidence for the sabotage hypothesis is provided by Feichter et al. (2022) and Bloomfield et al. (2021).

implement them. While there might be good theoretical reasons to utilise RPE-based compensation schemes, they tend to amplify the managers' tendency to engage in over-aggressive behaviour. Managers already make aggressive decisions without being incentivised by competitor-oriented compensation schemes (Armstrong and Collopy, 1996). The results of our study imply that decisions under RPEs would result in even more significant deviations from profit-maximising behaviour. Therefore, before introducing RPE-based executive compensation, business owners should consider its potentially undesirable side effects.

Moreover, our evidence of over-aggressive behaviour in both APE and RPE contracts may cast doubt on the effectiveness of RPE-based compensation systems as a strategic commitment device. Even managers incentivised by an APE-based compensation system exhibit over-aggressive behaviour when they are in a disadvantageous position. However, this behaviour counteracts the mechanism that makes RPE-based bonuses attractive from a strategic delegation perspective.

Our results could also be relevant for competition policy. Our findings imply that the introduction of RPE-based compensation schemes improves allocative efficiency, as managers would choose higher output levels because of RPE-based compensation. In oligopoly markets, this would lead to falling prices and, thus, higher consumer surplus. In this respect, antitrust authorities might be sympathetic to the introduction of such compensation schemes. Furthermore, it could be conjectured that RPE-based contracts could also have an impact on the likelihood of collusive behaviour. However, further research is needed to investigate this.

As with all experimental studies, there are some potentially critical issues with our methodology. We use a specific framework of a game with sequential moves (Stackelberg market). An alternative approach would be to study managerial decisions in a simultaneous game. A repeated game with simultaneous moves would provide better opportunities for subjects to punish other subjects for their choices. As pointed out by Brandts and Charness (2011), the extent of punishment could be substantially lower in the strategy method. However, assuming that RPE-based compensation systems influence punishment behaviour, our measurement of the effects of RPE-based compensation tends to represent the lower bound of what one can expect in games with simultaneous moves. Moreover, games with simultaneous moves provide further difficulties in eliciting entire strategies and categorising the managers' responses (Müller and Tan, 2011). Therefore, we believe that the strategy method is particularly well suited to analyse the effects of compensation systems on managers' strategic decisions.

Another potential criticism of our approach is the use of the "lab-in-the-field" method in the form of an online experiment. While online experiments offer new research opportunities and are becoming increasingly popular, they also carry the risk of reduced control and pose methodological challenges, especially in interactive designs. However, Arechar et al. (2018) report that behavioural patterns of cooperation and punishment in the laboratory are replicable online. Thus, we are convinced that our online experiment provides valid results and is a good alternative to a laboratory experiment, especially in times of pandemics. Nevertheless, we are aware of the various challenges associated with conducting an online experiment and discuss them in Appendix 2.B.

Finally, the question arises whether it is possible to learn something about the behaviour of managers in the real world from the behaviour of the subjects in our online experiment. One may question whether our experimental environment is the appropriate testing ground for our hypotheses. We claim that it is, since subjects in our market experiment act as managers who are paid based on their decisions. Beyond that, following the idea of a modified experimental claim by Bardsley (2010), we argue that our experimental environment is in the test domain of the theory unless there is a difference between our experimental environment and the intended domain that can reasonably be expected to make behaviour in the intended domain significantly more consistent with the theory. The question arises whether the subjects in our sample are suitable to test our hypotheses regarding the decision-making of managers incentivised by different types of compensation schemes. Unlike most market experiments whose participants are students, we employ a general population sample. Although our sample selection addresses the usual criticism of using students as subjects, we still need to consider the possibility that the behaviour of managers in the real world may differ from the behaviour of subjects in our general population sample. In other words, managers in the real world might exhibit less aggressive behaviour, i.e., they would tend to choose lower quantities. Armstrong and Collopy (1996), however, show that the tendency to engage in aggressive behaviour is increasing with management education. In addition, recent studies suggest that more competitive individuals are more likely to move into high-level professional or managerial positions (Buser et al., 2021; Urbig et al., 2019). Lastly, reports of the behavioural evaluations of upper management point out the prevalence of narcissistic traits among CEOs that are associated with more antagonistic behaviour (Cragun et al., 2019). In conclusion, existing evidence suggests that real-world managers tend to be more aggressive rather than less aggressive compared to the general population.

2.6 Conclusion

The increasing use of RPE-based compensation systems as the basis for executive compensation by organisations, such as the S&P 500 companies, stands in stark contrast to the knowledge of the potential impact of this type of compensation on the behaviour of managers. Although previous research provides some empirical evidence of possible negative effects on the profits of companies that use RPE-based compensation schemes, it has not yet been proven whether this is due to the causal effects of these compensation schemes on executive behaviour.

The results of our experiment show a causal effect of RPE-based compensation schemes on executive behaviour. While the results of our market experiment are consistent with the theoretical predictions based on payoff maximisation, i.e. the RPE-based compensation scheme results in higher quantities than the APE-based compensation scheme in quantity competition, we also find evidence that subjects are more likely to sacrifice their own compensation to reduce a competitor's profits, particularly in an RPE-based compensation system. Our results suggest that business owners deciding whether to implement RPE-based compensation systems in their organisations should also consider their potentially undesirable effects on managerial behaviour.

We see our experiment as a solid starting point for future research on the causal effects of RPE-based compensation schemes on managers' decision-making behaviour. One possibility for fruitful future research is to analyse other types of oligopoly markets where the nature of competition is different, i.e. price competition versus quantity competition, the number of firms in the market or simultaneous move games. Furthermore, it could be investigated whether the over-aggressive behaviour observed in our experiment is related to the subjects' unobserved preferences, e.g., social orientation.

Appendix 2.A: Tables

Table 2.A.1: Demographics: Overall Sample and Subsamples

Characteristic	**Overall** N = 197	**Downward slope** N = 141	**Random slope** N = 17	**Upward Slope** N = 39
Gender				
Female	121 (61%)	80 (57%)	11 (65%)	30 (77%)
Male	75 (38%)	61 (43%)	5 (29%)	9 (23%)
No Data	1 (0.5%)	0 (0%)	1 (5.9%)	0 (0%)
Country				
Ireland	14 (7.1%)	9 (6.4%)	1 (5.9%)	4 (10%)
United Kingdom	171 (87%)	125 (89%)	14 (82%)	32 (82%)
United States	12 (6.1%)	7 (5.0%)	2 (12%)	3 (7.7%)
Level of Education				
Doctorate degree	4 (2.0%)	3 (2.1%)	0 (0%)	1 (2.6%)
Graduate degree	34 (17%)	25 (18%)	4 (24%)	5 (13%)
High school diploma	30 (15%)	21 (15%)	4 (24%)	5 (13%)
No Data	32 (16%)	24 (17%)	2 (12%)	6 (15%)
Technical college	15 (7.6%)	10 (7.1%)	2 (12%)	3 (7.7%)
Undergraduate degree	82 (42%)	58 (41%)	5 (29%)	19 (49%)
Student				
No	115 (58%)	80 (57%)	13 (76%)	22 (56%)
No Data	34 (17%)	25 (18%)	2 (12%)	7 (18%)
Yes	48 (24%)	36 (26%)	2 (12%)	10 (26%)
AGE	31 (25, 41)	31 (24, 41)	33 (24, 42)	31 (28, 37)
EmploymentStatus				
Due to start a new job	2 (1.0%)	1 (0.7%)	0 (0%)	1 (2.6%)
Full-Time	76 (39%)	52 (37%)	10 (59%)	14 (36%)
No Data	34 (17%)	27 (19%)	1 (5.9%)	6 (15%)
Not in paid work	20 (10%)	14 (9.9%)	1 (5.9%)	5 (13%)
Other	13 (6.6%)	11 (7.8%)	0 (0%)	2 (5.1%)
Part-Time	30 (15%)	21 (15%)	2 (12%)	7 (18%)
Unemployed (and job seeking)	22 (11%)	15 (11%)	3 (18%)	4 (10%)
TimeTaken	25 (17, 34)	27 (18, 35)	24 (15, 34)	20 (16, 28)
Bonus	7.00 (4.99, 8.13)	7.00 (4.99, 8.29)	7.21 (5.34, 7.62)	7.00 (4.22, 7.85)

[1] n (%); Median (IQR)

Appendix 2.B: Challenges of Running Online Experiment

The interface has been programmed using LIONESS platform (Giamattei et al., 2020) along with standard tools for website design (HTML, CSS and JavaScript). The participants were recruited via Prolific.ac (Palan and Schitter, 2018). Although online experiments are becoming more acceptable in experimental economics[18] and seem inevitable during the COVID-19 restrictions, they also pose considerable challenges from a methodological perspective. This subsection briefly describes these challenges and explores their implications for the experimental design.

The largest challenge is data quality. Although Prolific is a generally well-rated platform for behavioural research[19], we have implemented additional checks to decrease the risks of inattentive respondents. These attention checks were in line with Prolific's guidelines (for examples, see Appendix 2.D and respective decision stages) and were included in the decision stages. All participants who had failed attention checks were not allowed to proceed to the matching stage and were excluded from the analysis. This measure has decreased the number of observations from 267 to 200.

The second challenge is time constraints. Long experiments and surveys have detrimental effects on response quality (Savage and Waldman, 2008) and may be too boring for the participants (Ambler et al., 2021). Additionally, due to Prolific's policy of linking guaranteed payment to median completion time, there was also a cost incentive to decrease the average time for finishing the experiment. We have attempted to do it in two ways. First, we have reduced the strategy space of the leaders to the nine choices indicated in Section 2.3.1 (compared to 12 choices in Müller and Tan (2011) and Huck et al. (2001)). Second, we have implemented a "delayed matching" protocol. Suppose a participant finishes the decision stages with no available opponents to match with her. In that case, her responses are stored until the next participant also completes all stages. Thus, she does not have to wait to be matched. These measures decreased the average completion time to 25 minutes and allowed new participants to join the experiment at different times.

[18]For example Arechar et al. (2018) find that behavioural patterns of cooperation and punishment are replicable online, which is the main interest of the proposed design.

[19]See Peer et al. (2017) and Pe'er et al. (2021) for comparisons, and Litman et al. (2021) for the discussion.

Appendix 2.C: Additional Analyses

In our experimental setting, some of the participants started with APE, and some with RPE. "Order" takes the value 1 for the responses under the initial contract and 0 for the responses for the subsequent contract.

Table 2.C.1: Estimated Linear Response Functions of Followers (including order effects)

	Model 1	Model 2
Intercept	33.594***	34.379***
	(1.012)	(0.968)
Q_L(Leader quantity)	−0.232***	−0.253***
	(0.032)	(0.031)
RPE	1.617*	
	(0.777)	
$RPE \times Q_L$ (Leader quantity)	0.060**	0.102***
	(0.021)	(0.010)
$Order$	−0.334	−0.288
	(0.388)	(0.382)
Num.Obs.	3546	3546
R2	0.119	0.117

Notes: Significance levels at *p < 0.05, **p < 0.01, ***p < 0.001. Cluster-robust standard errors are in parentheses.

Table 2.C.2: Estimated Linear Response Functions of Followers (between-subject comparison)

	Model 1	Model 2
Intercept	31.984***	33.185***
	(1.439)	(1.041)
Q_L(Leader quantity)	−0.184***	−0.215***
	(0.049)	(0.038)
RPE	2.190	
	(2.066)	
$RPE \times Q_L$ (Leader quantity)	0.036	0.092***
	(0.065)	(0.026)
Num.Obs.	1773	1773
R2	0.080	0.077

Notes: Significance levels at *p < 0.05, **p < 0.01, ***p < 0.001. Cluster-robust standard errors are in parentheses.

Table 2.C.3: Determinants of the Probability of Over-aggressive Behaviour: Logistic Regressions and Linear Probability Models (including order effects)

	RE Logit 1	LPM 1	RE Logit 2	LPM 2
RPE	0.833***	0.097***	0.877***	0.079***
	(0.100)	(0.020)	(0.164)	(0.020)
Behind	2.198***	0.269***	2.238***	0.251***
	(0.111)	(0.026)	(0.161)	(0.028)
RPE × *Behind*			−0.071	0.037
			(0.205)	(0.028)
Order	0.178	0.019	0.178	0.019
	(0.097)	(0.020)	(0.097)	(0.020)
Intercept	−3.405***	0.086***	−3.432***	0.097***
	(0.201)	(0.021)	(0.217)	(0.020)
Num.Obs.	3546	3546	3546	3546
AIC	3014.5	4032.8	3016.4	4033.2
BIC	3045.4	4063.6	3053.5	4070.2

Notes: Significance levels at *p < 0.05, **p < 0.01, ***p < 0.001. Logistic regressions (RE Logit 1-2): Dependent variable Logit($Pr(Y_{ij} = 1)$). Coefficients are in log-odds for intercept and log-odds ratios for predictors. Linear probability models (LPM 1-3): Dependent variable $Pr(Y_{ij} = 1)$. Coefficients are in the marginal probabilities. Cluster-robust standard errors (for LPMs) are in parentheses.

Table 2.C.4: Determinants of the Probability of Over-aggressive Behaviour: Logistic Regressions and Linear Probability Models (between-subject comparison)

	RE Logit 1	LPM 1	RE Logit 2	LPM 2	RE Logit 3	LPM 3
RPE	0.609*	0.082*	1.054**	0.114**	1.690***	0.119***
	(0.294)	(0.040)	(0.378)	(0.039)	(0.461)	(0.035)
Behind			2.493***	0.287***	3.089***	0.293***
			(0.174)	(0.031)	(0.307)	(0.043)
RPE × *Behind*					−0.906*	−0.011
					(0.359)	(0.062)
Intercept	−1.739***	0.247***	−3.624***	0.088***	−4.089***	0.084***
	(0.230)	(0.028)	(0.332)	(0.025)	(0.393)	(0.020)
Num.Obs.	1773	1773	1773	1773	1773	1773
AIC	1838.0	2229.0	1559.0	2045.4	1554.3	2047.4
BIC	1854.4	2245.4	1580.9	2067.4	1581.7	2074.8

Notes: Significance levels at *p < 0.05, **p < 0.01, ***p < 0.001. Logistic regressions (RE Logit 1-3): Dependent variable Logit($Pr(Y_{ij} = 1)$). Coefficients are in log-odds for intercept and log-odds ratios for predictors. Linear probability models (LPM 1-3): Dependent variable $Pr(Y_{ij} = 1)$. Coefficients are in the marginal probabilities. Cluster-robust standard errors (for LPMs) are in parentheses.

Additional model specifications: We check the robustness of our results with regard to changes in econometric specification. In the main body of the chapter, we have presented the simplest generalised linear mixed model with random intercepts on the individual level. As a robustness check, we also run GLMMs with random coefficients for contracts (η_{1i}) and behindness (η_{2i}). Thus, the complete model could be summarised as

$$\text{Logit}(Pr(Y_{ij}=1)) = \beta_{00}+(\beta_{10}+\eta_{1i})RPE_{ij}+(\beta_{20}+\eta_{2i})Behind_j+\beta_3(RPE_{ij}\times Behind_j)+\eta_{0i}$$

$$\begin{pmatrix}\beta_{0i}\\ \beta_{1i}\\ \beta_{2i}\end{pmatrix} \sim N\left(\left(\begin{pmatrix}0\\0\\0\end{pmatrix}, \begin{pmatrix}\sigma^2_{\beta_{0i}} & \rho_{\beta_{0i}\beta_{1i}} & \rho_{\beta_{0i}\beta_{2i}}\\ \rho_{\beta_{1i}\beta_{0i}} & \sigma^2_{\beta_{1i}} & \rho_{\beta_{1i}\beta_{2i}}\\ \rho_{\beta_{2i}\beta_{0i}} & \rho_{\beta_{2i}\beta_{1i}} & \sigma^2_{\beta_{2i}}\end{pmatrix}\right)\right), \text{ for subject i} = 1..\text{n}$$

Table 2.C.5 presents this model as well as its variations (i.e. including/excluding the slopes and/or the interaction term ($RPE \times Behind$). Our conclusions from Section 2.4 remain valid under any model specification. Including the interaction component does not significantly improve the model fit in all but one model specification. The increase in conditional probabilities of observing over-aggressive behaviour under RPE contract ranges from 10% (RE Logit 1) to 13% (RE Logit 6).

Table 2.C.5: Determinants of the Probability of Over-aggressive Behaviour: Additional Model Specifications (Logistic regressions)

	RE Logit 1	RE Logit 2	RE Logit 3	RE Logit 4	RE Logit 5	RE Logit 6
RPE	0.845***	0.893***	1.286***	1.837***	1.489***	1.783***
	(0.100)	(0.163)	(0.245)	(0.351)	(0.277)	(0.369)
Behind	2.194***	2.238***	2.528***	2.913***	2.299***	2.558***
	(0.111)	(0.161)	(0.129)	(0.217)	(0.307)	(0.374)
RPE × *Behind*		−0.078		−0.629*		−0.407
		(0.205)		(0.270)		(0.326)
Intercept	−3.318***	−3.347***	−4.057***	−4.434***	−4.122***	−4.337***
	(0.195)	(0.211)	(0.294)	(0.354)	(0.318)	(0.373)
Num.Obs.	3546	3546	3546	3546	3546	3546
Random effects:						
Intercept(η_{0i})	✓	✓	✓	✓	✓	✓
Contract (η_{1i})			✓	✓	✓	✓
Behindness (η_{2i})					✓	✓
AIC	3015.8	3017.7	2886.2	2882.7	2671.9	2672.4
BIC	3040.5	3048.5	2923.3	2925.9	2727.5	2734.1

Notes: Significance levels at * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
Coefficients are in log-odds for intercepts, log-odds ratios for predictors.

Table 2.C.6: Determinants of the Probability of Over-aggressive Behaviour: Logistic Regressions and Linear Probability Models (restricted sample analysis: only downward-sloping group)

	RE Logit DS 1	RE Logit DS 2	LPM DS 1	LPM DS 2
RPE	0.947***	0.687***	0.098***	0.060**
	(0.129)	(0.195)	(0.013)	(0.019)
$Behind$	1.309***	1.059***	0.136***	0.098***
	(0.132)	(0.193)	(0.013)	(0.019)
$RPE \times Behind$		0.443		0.076**
		(0.255)		(0.026)
Intercept	−3.467***	−3.316***	0.105***	0.126***
	(0.264)	(0.276)	(0.024)	(0.025)
Num.Obs.	2538	2538	2538	2538
AIC	1948.0	1947.0	1919.7	1918.8
BIC	1971.3	1976.2	1948.9	1953.8

Notes: Significance levels at * p < 0.05, ** p < 0.01, *** p < 0.001.
Logistic regressions (RE Logit DS 1-2) include random intercepts on the individual level. Coefficients are in log-odds for intercept, log-odds ratios for predictors.
Linear Probability models (LPM DS 1-2): Dependent variable $Pr(Y_{ij} = 1)$. Coefficients are in the marginal probabilities.

Appendix 2.D: Instructions

Experimental instructions are presented in the sequence they are shown to participants (except pages 5-6 - as described in the main body of the chapter, the order was randomised for each participant). The content of each page can be summarised as follows:

1. Introduction to the experiment.

2. Information about the market environment, introduction to the calculator and control questions. By moving the sliders, participants change quantities and receive immediate feedback on their profits, other firm's profits, and the resulting compensation under both contracts. Participants can proceed only after they have answered the control questions correctly.

3. Information about payoffs, matching and exchange rates.

4. Practice round to describe how creating the response plan works. If the information is unclear, participants have an opportunity to see the description again.

5. First payoff-relevant rounds as the follower. This page contains an attention check: "Please write the following number in this field: 22".

6. Second payoff-relevant rounds as the follower. This page contains an attention check: "Please write the following number in this field: 11".

7. Announcement of Leader Quantity rounds.

8. First payoff-relevant rounds as the leader (there were two rounds like this, but the pages are identical except for the contracts).

9. The final page if the participant has not been matched (i.e. if there were any available participants). Could be refreshed to see if they have been matched.

10. The final page (if the participant has been matched), along with a calculator to check the payoff.

You are about to take part in a scientific game where you can win money.

By carefully choosing your decisions, you will be able to earn from **0 to 21 GBP in addition to a 2.20 GBP participation fee.**

Throughout this study, there would two attention checks.
If you fail both of them you will not receive the participation fee.
If you fail one of them, you will receive the participation fee, but will not receive the additional payments.
If you don't fail the attention checks, you will be matched with another participant and will receive the additional payments based on your and your opponent's decisions.

At the end of the game, you will receive a **CODE** that you can plug into prolific.co software to receive your payment.

We guarantee that we will treat all information we receive from you confidentially. The game is anonymous. You can cancel at any time, but you will not receive a payout.

By clicking "Continue", you consent to participate in this study.
The next page will explain the environment of the scientific game.

Please enter your **PROLIFIC ID:**

Continue

Explanation of the environment:

Firms' Profit Calculator

Firm A chooses: 25

0 10 20 30 40 50 60 70 80

Firm B chooses: 29

0 10 20 30 40 50 60 70 80

Firm Profit A:	**650**
Firm Profit B:	**754**

Total production is below 80.

General setting:

In this game, firms A and B compete in a market for some good X. Each of the two firms produces a certain quantity of good X.
The price of good X is:
Price = 80- (quantity produced by firm A + quantity produced by firm B)
The profit of each firm is given by:
Profit = Quantity produced by the firm * Price

In both firms, the decision about the quantity produced is made by a manager. Throughout the experiment, you are the manager of firm B at one time and the manager of firm A at another time.

Firm A produces its quantity of good X **first**. Then firm B produces its quantity of good X **in response.** The profits of each of the two firms depend on the quantities produced by both firms.

How the calculator works:

Suppose you change the position of the slider for any firm. In that case, you can see the new profits resulting from that specific combination of quantities. (Profit firm A and Profit firm B).
Note: If the total output by both firms exceeds 80, both firms will earn 0 profits.

Below you can find several questions about the game. You will only be able to proceed if you answer these questions correctly. You can find all answers by using the calculator and changing the position of the slider.

Suppose **firm A** chooses **25**, how much profit would **firm B** make if it chooses **27**?

756

Suppose **firm A** chooses **40** and you think of specifying a response of **30 for firm B**. If you decide to increase your production as firm B to **31**, then the Profit of firm A will...

Decrease

Increase

Suppose **firm A** chooses **25** and you plan to specify a response of **28**. If you change your strategy to **29**, then your profit decrease by **2**, but the profit of **firm A** will decrease by?

25

Continue

We are ready to start the game.

Description of your payments

- If you take your decisions seriously, you will receive 2.2 GBP as your participation fee.
- There would be two attention checks in the decision stages. If you fail both of them, you will not receive the participation fee.
- Your additional payment will consist of the profit of the firm you are responsible for and bonus payment.
- Each round will provide instructions and details about your bonus scheme and a calculator to help you with your choices.
- The exchange rate for this experiment is set at 100 Experimental points (EP) = 1 GBP.

Your decisions

- Over the next four rounds, you will be a manager and have to make decisions regarding the quantities of the firm you are responsible for.

- In the first two rounds, you will be a manager of Firm B, and you will be asked to create responses for 9 possible choices of the other participant.
- These rounds will differ on the bonus scheme (called Orange and Green contracts).

- In the last two rounds, you will be a manager of Firm A. You will be asked to choose one of 9 possible starting quantities that another participant would respond to.
- These rounds will differ based on the contract of the responding firm

Description of the matching

- If you do not fail any attention checks, after you have completed all decision stages, you will be matched with another participant who has also finished all these stages.
- Your role and payment scheme will be chosen at random and matched with the responses of another participant.
- Suppose no other participant has finished all the stages. In that case, your responses will be stored and matched as soon as another participant finishes.

All your decisions can influence your and another participant's additional payments.
These payments can be significantly higher than the participation fee.
The next page will provide an example of matching and the resulting outcomes.

Continue to the example

This page provides an example.

In the following two rounds, you will be asked to construct a response plan for Firm B.

Suppose you have specified the following plan for Firm B:

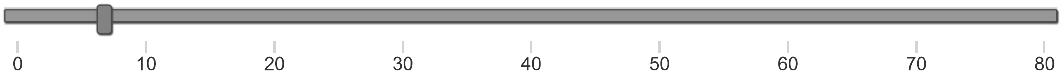
- **If Firm A produces 20 units, my firm (Firm B) chooses 40.**
- **If Firm A produces 30 units, my firm (Firm B) chooses 35.**

If a participant you are matched with chose to produce 20 units as Firm A, then, using your response plan above, Firm B produces 40 units. This results in your ADDITIONAL payment being 800 EP (or 8.00 GBP) and your opponent's payment being 400 EP (or 4.00 GBP).

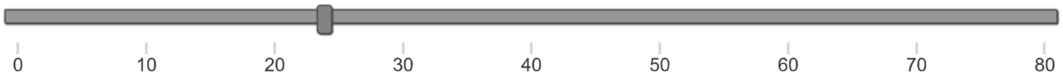
The following two rounds will also include two different BONUS schemes.

Firms' Profit Calculator

Firm A chooses: 7



Firm B chooses: 24



Firm Profit A:	**343 EP**
Firm Profit B:	**1176 EP**

Total production is below 80.

Continue to decision stages.

Back to game description.

Instructions:
In this stage, **you are the manager of firm B**. You need to construct a response plan for **firm B**. This includes creating a response for each of the possible decisions of firm A. The calculator still works as previously. In addition to calculating profits, it also calculates your bonus payment and the payment to the **manager of firm A (Participant you will be matched with)**.

To complete this stage, you will need to specify quantity choices for each possible quantity of firm A. In the matching stage, these choices would determine your response to your opponent's decision and **will be the basis of your final payment if this round is chosen.**

In this round, you will be paid with Orange Contract**.** This round can be the basis of your additional payment.

Your total payment under the Orange contract is:
Profits of Firm B + 100+ 0.33 * (Profits of Firm B - Profits of Firm A)
where **100+0.33 * (Profits of Firm B - Profits of Firm A)** is a bonus payment if your profits are positive.
Your bonus payment can be negative, but your total payment will never be below 0.

Your opponent's total payment is:
Profits of Firm A + 100
In the matching stage, Firm A's options will be restricted to these numbers: (1,7,14,20,27,33,40,48,56).

Firms' Profit Calculator

Firm A (Another participant) chooses:

0 10 20 30 40 50 60 70 80

Firm B (You) chooses:

0 10 20 30 40 50 60 70 80

Payments to you and the participant you are matched with:

	Profits	Bonus	Total
Manager of Firm A (another participant):			EP
Your Payment under current contract*:			EP

What would be your choice as firm B, if firm A chooses **1**

What would be your choice as firm B, if firm A chooses **7**

What would be your choice as firm B, if firm A chooses **14**

What would be your choice as firm B, if firm A chooses **20**

What would be your choice as firm B, if firm A chooses **27**

What would be your choice as firm B, if firm A chooses **33**

Please write the following number in this field: **22.**

What would be your choice as firm B, if firm A chooses **40**

What would be your choice as firm B, if firm A chooses **48**

What would be your choice as firm B, if firm A chooses **56**

Continue

Instructions:
In this stage, **you are the manager of firm B**. You need to construct a response plan for **firm B**. This includes creating a response for each of the possible decisions of firm A. The calculator still works as previously. In addition to calculating profits, it also calculates your bonus payment and the payment to the **manager of firm A (Participant you will be matched with)**.

To complete this stage, you will need to specify quantity choices for each possible quantity of firm A. In the matching stage, these choices would determine your response to your opponent's decision and **will be the basis of your final payment if this round is chosen.**

In this round, you will be paid with Green Contract. This round can be the basis of your additional payment.

Your total payment under the Green Contract:
Profits of Firm B + 100

where 100 is a bonus payment if your profits are positive.

Your opponent's total payment is:
Profits of Firm A + 100
In the matching stage, Firm A's options will be restricted to these numbers: (1,7,14,20,27,33,40,48,56).

Firms' Profit Calculator

Firm A (Another participant) chooses:

0 10 20 30 40 50 60 70 80

Firm B (You) chooses:

0 10 20 30 40 50 60 70 80

Payments to you and the participant you are matched with:

	Profits	Bonus	Total
Manager of Firm A (another participant):			EP
Your Payment under current contract*:			EP

What would be your choice as firm B, if firm A chooses **1**

2

What would be your choice as firm B, if firm A chooses **7**

3

What would be your choice as firm B, if firm A chooses **14**

3

What would be your choice as firm B, if firm A chooses **20**

3

What would be your choice as firm B, if firm A chooses **27**

3

Please write the following number in this field: **11.**

11

What would be your choice as firm B, if firm A chooses **33**

44

What would be your choice as firm B, if firm A chooses **40**

43

What would be your choice as firm B, if firm A chooses **48**

3

What would be your choice as firm B, if firm A chooses **56**

2

Continue

Chapter 3

The Impact of Relative Performance Evaluation in Executive Compensation on Market Efficiency and Collusive Behaviour: Experimental Evidence[†]

Abstract
In this experimental study, we investigate the effects of relative performance evaluation (RPE) in managerial compensation on market efficiency and collusive behaviour. In our experiment, managers' compensation is based either on their own firm's profits or on relative profits, i.e., the difference between their own firm's profits and those of a competitor. We further distinguish between two environments: one permitting only tacit collusion and the other allowing managers to collude explicitly by forming agreements prior to the play. The results show that RPE-based bonuses improve allocative efficiency, especially in the absence of explicit collusion. Although the positive effects of RPEs on allocative efficiency appear to be less pronounced when explicit agreements are possible, there is evidence that RPEs undermine the stability of such agreements. Therefore, our findings indicate that the nature of managerial compensation can be welfare-enhancing and serve as an internal force that destabilises cartels.

[†] *Co-written with Werner Bönte.*

3.1 Introduction

The determinants of firms' collusive behaviour have always been the focus of industrial economics, as they influence allocative efficiency in oligopolistic markets. Theoretical studies have identified many factors, such as product heterogeneity (Deneckere, 1983) or capacity constraints (Brock and Scheinkman, 1985), that may facilitate or hinder collusive behaviour. Analyses of determinants of collusive behaviour are usually based on the assumption that companies maximise their own profits or, in the case of cartels, the joint profits of the cartel members (Feuerstein, 2005b; Ivaldi et al., 2003). In practice, however, remuneration schemes for managers have become increasingly established in which executive compensation is determined not only by absolute performance evaluation (APE), e.g., the profit of the manager's company itself, but also by relative performance evaluation (RPE), e.g., the difference to the profit of competing companies. Executive compensation of more than half of the S&P 500 companies is based on some form of RPE (Bizjak et al., 2022).

As shown in the rather extensive literature on strategic delegation (Vickers, 1985; Miller and Pazgal, 2002; Jansen et al., 2008), firm owners can use RPE-based compensation schemes to induce more aggressive behaviour by managers in product markets, which in turn can lead to a more advantageous market position for a firm. Based on these theoretical insights, it can be assumed that RPE-based remuneration of managers tends to discourage collusive behaviour, implying that RPE-based compensation schemes improve allocative efficiency in oligopolistic markets. In fact, Matsumura and Matsushima (2012) demonstrate that maximising relative rather than absolute profits in an infinitely repeated Cournot duopoly destabilises collusive behaviour by increasing the incentive for management to deviate from any collusive agreements. However, there is virtually no empirical evidence of the link between RPE-based remuneration and collusive behaviour. The results of a study based on firm-level data by Bloomfield et al. (2023) suggest that firms in concentrated industries that form cartels are more likely to use relative performance evaluation (RPE) for their top managers. This finding seems to contradict the theoretical predictions. However, the correlations found cannot be interpreted as causal relationships because, as Bloomfield et al. (2023) themselves emphasise, RPE-based compensation could be used by cartel members for other unobserved reasons[1].

Therefore, it is an open empirical question whether RPE-based compensation schemes have causal effects on collusive behaviour by making tacit collusion more or less likely or even stabilising or destabilising explicit cartels. Since the inherent endogeneity problems of empirical studies based on observational data make it considerably more difficult to

[1] For example, according to Holmstrom (1979)'s informativeness principle, RPE could be used to better monitor the unobservable actions of the CEOs, aid with talent retention (De Angelis and Grinstein, 2020) or insulate risk-averse CEOs from industry shocks (Gibbons and Murphy, 1990). For a comprehensive review, see Edmans et al. (2017), Chapter 3.4.

identify causal effects, we choose a different approach and investigate these causal effects in the context of an economic experiment. Specifically, we conduct an economic experiment in which participants in a repeated quantity duopoly make quantity decisions. Our first treatment is the type of compensation, as either APE-based or RPE-based bonuses determine participants' rewards. We implement the experiment as a sequence of supergames, where participants play two supergames under each type of compensation scheme. Hence, in this treatment, we use a within-subjects design to observe participants' choices under all possible combinations of the two bonuses (i.e., APE vs APE, APE vs RPE, RPE vs APE and RPE vs RPE). In the second treatment, we distinguish between tacit and explicit collusion by either allowing or not allowing communication between managers. If communication is allowed, the participants can coordinate their actions via chat before each supergame, meaning they can make explicit agreements and form cartels. If communication is not allowed, managers can only make tacit agreements. By analysing the text of chat messages, when communication is allowed, it is possible to determine whether cartel agreements are being made and whether the participants deviate from them in their subsequent decisions on quantities. For the second treatment, we use a between-subjects design so that subjects can either communicate with each other or not. Based on a theoretical analysis of the market environment in our experiment, we hypothesise that an increase in the number of managers incentivised by RPE-based bonuses leads to an increase in market quantity, has a negative impact on tacit collusion and makes deviation from explicit cartel agreements more likely.

In cases where there is no communication between managers, the results of our experiment confirm that RPE-based compensation improves allocative efficiency, as we observe higher market quantities when the number of managers with RPE-based compensation increases. This finding suggests that RPE-based bonuses have a negative impact on tacit collusion. The chosen output levels increase even if only one of the two managers receives RPE-based compensation. Our results also show that the profits of both companies decrease due to RPE-based compensation, regardless of whether one or both companies use this type of executive compensation. This result contradicts the predictions of theoretical studies, which suggest that in the case of asymmetric remuneration systems, the firm with RPE-based remuneration should be in a more favourable position and achieve higher profits (Jansen et al., 2008). This contradiction can be explained by the fact that in our experiment, managers with APE-based compensation also choose relatively large quantities, suggesting that these managers retaliate when the competitor chooses large quantities. Although overall efficiency increases with the number of managers incentivised by RPE-based compensation, we still observe a certain degree of tacit collusion in all contract combinations.

If communication between managers is possible and managers can, therefore, make explicit agreements, we observe significantly lower market quantities than in the case where communication is impossible. We also find that RPE-based compensation has no significant effect on the rate of explicit collusion, as our results show that collusive agreements are achieved in the majority of the markets. Thus, our results confirm existing experimental studies that have also shown the importance of communication for collusive behaviour (Fonseca and Normann, 2012; Hanaki and Ozkes, 2022). The effect of communication overshadows the pro-competitive effects of RPE on allocative efficiency. However, we do find some suggestive evidence that RPE contracts provide sufficient incentives for deviation after reaching the agreement. Furthermore, our results also show that the *average* gain of communication is larger under RPE-based compensation than it is under APE-based compensation.

Our study contributes to experimental research on the determinants of market efficiency, tacit collusion and cartel stability by investigating the impact of executive compensation on collusive behaviour. While the relevance of various determinants of collusive behaviour has been examined in economic experiments (Engel, 2007, 2015), our experiment is the first study to focus specifically on the effects of RPE-based executive compensation, offering further insights into achieving more competitive outcomes. While theoretical research states that relative performance (or relative profits) bonuses increase the intensity of competition and destabilise collusion (Jansen et al., 2008; Matsumura and Matsushima, 2012), these propositions have not yet been examined in economic experiments. We confirm these theoretical conjectures empirically.

Our study is also broadly related to the field of strategic delegation and managerial compensation (Vickers, 1985; Miller and Pazgal, 2002; Jansen et al., 2008). Several experimental studies have been conducted in this field, but most of them have focused on examining owners' decisions regarding the adoption of certain executive compensation schemes (Huck et al., 2004a; Georgantzís et al., 2008; Du et al., 2013; Kim, 2022). Our approach differs from this line of experimental research because we do not study owners' behaviour but focus exclusively on identifying the *causal effects* of RPE-based compensation schemes on managers' decisions. In other words, owners' decisions are entirely exogenous in our experimental design to rule out any potential problems with endogeneity.

The rest of this chapter is organised as follows: Section 3.2 covers the theoretical framework, briefly describes existing experimental studies, and establishes testable hypotheses. Section 3.3 explains our experimental design and methodology. Sections 3.4 and 3.5 present our results and subsequent discussion. We conclude our study and directions for future research in Section 3.6.

3.2 Theoretical Background

Several theoretical papers have explored how incentives based on relative performance (like relative profits) influence the intensity of competition and stability of collusion.

Jansen et al. (2008) shows bonuses based on relative profits result in elevated quantity (i.e., more aggressive choices) choices in a one-shot Cournot environment. Lungren posits that executive compensation based on relative profits rather than absolute profits leads to a zero-sum game among firms in an industry, resulting in firms no longer having the incentive to collude, explicitly or tacitly, on prices or quantities. The basic idea of Lundgren's model is that successful collusion increases firms' absolute profits but not their relative profits. Matsumura and Matsushima (2012) analyse a duopoly model where two firms choose their outputs to maximise relative profits rather than their absolute profits in an infinitely repeated Cournot duopoly. Matsumura and Matsushima (2012) show that an increase in the degree of competition in the form of RPE-based managerial compensation destabilises collusion. Moreover, they show that the main result holds even in the case of optimal punishment or cost heterogeneity between firms. Guigou and de Lamirande (2015) make further contributions by investigating the impact of asymmetry concerning APE- and RPE-based compensation schemes on the possibility of collusion between managers. Using the concept of balanced temptation introduced by Friedman (1971), they find that incentive asymmetry may make collusive agreements more stable.

This section briefly summarises the theoretical framework behind Jansen et al. (2008), Matsumura and Matsushima (2012) and Guigou and de Lamirande (2015). We then discuss its implications regarding the symmetric and asymmetric adoption of APE- and RPE-based executive compensation schemes and derive resulting testable hypotheses.

3.2.1 One-shot Game: Symmetric and Asymmetric Manager Remuneration

We establish the general setting of a game by first considering possible compensation schemes and the resulting market outcomes in a one-shot game. In general, we assume manager i's compensation scheme (V_i) to consist of a fixed part (f_i) and a bonus (b_i) linked proportionally (ω_i) to performance:

$$V_i = f_i + \omega_i b_i$$

We normalise $f_i = 0$ and $\omega_i = 1$ and assume that there are two types of bonuses, namely the relative performance evaluation (b^{RPE}) and the absolute performance evaluation (b^{APE}). The APE-based bonus focuses exclusively on the profits of the firm for which the manager works (Π_i), while the RPE-based bonus also considers the profits of the competing firm j (Π_j). The APE and RPE-based bonuses are given by:

Absolute profit evaluation (APE): $$b^{APE} = \Pi_i \tag{3.1}$$

Relative profit evaluation (RPE): $$b^{RPE} = \Pi_i + \gamma(\Pi_i - \Pi_j) \tag{3.2}$$

where $\gamma \in (0, 1]$ is the weight of the RPE part of the compensation. The RPE component of the remuneration scheme is positively related to the firm's own profit and negatively to the competitor's profit. We make three further simplifying assumptions about the market conditions. First, following previous theoretical studies on the effects of RPE-based compensation on collusion, we consider a game played by two managers with given APE or RPE-based contracts. They compete à la Cournot and decide on output quantities on behalf of their respective firms. Second, in line with previous theoretical studies, we assume that the metric for performance evaluation is based solely on firms' profits. Third, we assume that there are only two possible choices for γ: either $\gamma = 0$ and the manager is remunerated according to the APE scheme, or $\gamma > 0$ and the manager's compensation includes the RPE component. Hence, we assume that the weight γ is identical for both managers. The model with asymmetric weights has been examined by Guigou and de Lamirande (2015).

Following Guigou and de Lamirande (2015) and Jansen et al. (2008), we assume that manager i receives compensation proportional to the difference in profits. However, in these studies, it is assumed that the bonus is given by $\Pi_i - \theta\Pi_j$, while we assume that the bonus is given by $(\Pi_i + \gamma(\Pi_i - \Pi_j))$. It is obvious that the two are related since θ can be written as $\theta = \frac{\gamma}{\gamma+1}$. This implies an identical best response function. However, our way of representing the bonus has two attractive features for the design of the experiment. First, it makes the RPE part of the bonus more explicit - making it clearer that a manager can only achieve higher compensation if the manager chooses higher output levels relative to the competing firm. Second, this structure ensures that if both managers choose the same output quantities, they will achieve the same compensation, regardless of the contract. Following previous research, we assume that the inverse demand is linear and given by:

$$P(q_i, q_j) = a - q_i - q_j,$$

where $a > 0$, P is price, and q_i is firm i's output. Firms have symmetric costs given by $C(q_i) = cq_i$. Accordingly, the firm i's profit is given by:

$$\Pi_i = (a - q_i - q_j - c)q_i \tag{3.3}$$

Substituting respective profit functions(3.3) into compensation schemes (3.1-3.2) and assuming that managers maximise their compensations yields the following managers' best response functions:

$$q_i^{*APE}(q_j) = \frac{a-c}{2} - \frac{q_j}{2} \tag{3.4}$$

$$q_i^{*RPE}(q_j) = \frac{a-c}{2} - \frac{1}{2+2\gamma}q_j \tag{3.5}$$

It is easy to see that for $\gamma = 0$, best response functions 3.4 and 3.5 are identical.

Moreover, a closer look at equation 3.5 reveals that for any $\gamma > 0$, the manager compensated under the RPE contract would choose higher quantities. Table 3.2.1 presents equilibrium quantities, profits, and managerial compensation resulting from the three different combinations of managers' compensation schemes, given that managers do not engage in collusive behaviours. Two symmetric cases exist: the traditional Cournot-Nash equilibrium (APE vs APE) and the equilibrium where both managers are paid under the RPE-based compensation system (RPE vs RPE). In the asymmetric case (APE vs RPE), the manager receiving the RPE-based bonus will choose higher quantities than in the simple Cournot duopoly, and the manager receiving the APE-based bonus will choose lower quantities. This increase in competitive aggressiveness is the key mechanism for the use of RPE as a commitment device, as postulated in the strategic delegation literature (Vickers, 1985; Jansen et al., 2008).

Table 3.2.1: Quantities, Profits, and Executive Compensation: Static Game

	APEvsAPE	**APEvsRPE**	**RPEvsRPE**
Quantities	$\frac{h}{3}, \frac{h}{3}$	$\frac{h(\gamma+1)}{4\gamma+3}, \frac{h(2\gamma+1)}{4\gamma+3}$	$\frac{h(\gamma+1)}{2\gamma+3}, \frac{h(\gamma+1)}{2\gamma+3}$
Profits	$\frac{h^2}{9}, \frac{h^2}{9}$	$\frac{h^2(\gamma+1)^2}{(4\gamma+3)^2}, \frac{h^2(\gamma+1)(2\gamma+1)}{(4\gamma+3)^2}$	$\frac{h^2(\gamma+1)^2}{(2\gamma+3)^2}, \frac{h^2(\gamma+1)^2}{(2\gamma+3)^2}$
Compensation	$\frac{h^2}{9}, \frac{h^2}{9}$	$\frac{h^2(\gamma+1)^2}{(4\gamma+3)^2}, \frac{h^2(\gamma+1)^3}{(4\gamma+3)^2}$	$\frac{h^2(\gamma+1)}{(2\gamma+3)^2}, \frac{h^2(\gamma+1)}{(2\gamma+3)^2}$

Note: Where $h \equiv (a - c)$.

The total market quantity is positively linked to the level of γ when one or both firms make use of RPE-based bonuses and the market quantities exceed the market quantity of the traditional Cournot duopoly if $\gamma > 0$. More precisely, the market quantity produced when both managers are incentivised by the RPE-based compensation scheme exceeds that of the asymmetric combination of compensation schemes, and the latter exceeds the market quantity when neither manager receives RPE-based compensation. This leads to our first theoretical result.

Hypothesis 1 *If the number of managers incentivised by RPE-based bonuses increases, market quantities increase.*

Hypothesis 1 is based on the one-shot game. If, on the other hand, the interaction is repeated, managers may achieve higher profits, provided the discount factors are sufficiently high. Therefore, we now turn to our analysis of repeated games and critical discount factors.

3.2.2 Repeated Game: Symmetric Manager Remuneration

Similar to the previous studies on collusion and its stability (Deneckere, 1983; Lambertini and Trombetta, 2002; Feuerstein, 2005b), we assume that firms resort to the Nash equilibria shown in Table 3.2.1 as part of the grim trigger strategy in an infinitely repeated game.[2] We first look at the symmetric case with both managers either incentivised by the RPE-based bonus (RPE vs RPE) or by the APE-based bonus (APE vs APE). We assume managers to play the above game over an infinite horizon and have a common discount factor δ. We derive a minimum critical discount factor δ^*, necessary to sustain collusive behaviour. In general, collusion is sustainable if

$$\delta > \delta^* = \frac{V^D - V^C}{V^D - V^E}$$

where V^C denotes the managerial payoff from collusive behaviour (in our case, this would be half of the monopoly output), V^D is a payoff from one-shot deviation (best-responding to half of the monopoly output), and V^E is the Nash equilibrium of the one-shot game which would be played as part of the grim trigger strategy. For the symmetric case, where both managers are incentivised by the RPE-based bonus, δ^* can be shown to be

$$\delta^* = \frac{(2\gamma + 3)^2}{4\gamma^2 + 20\gamma + 17} \tag{3.6}$$

For the symmetric case, where both managers are incentivised by the APE-based bonus, implying $\gamma = 0$, δ^* is equal to $\frac{9}{17}$, which is the critical discount factor in the traditional Cournot game (APE vs APE). It is also clear that δ^* is increasing for $\gamma > 0$, implying that RPE contracts raise the critical level of discount factor and, thus, make collusive agreements less stable.

3.2.3 Repeated Game: Asymmetric Manager Remuneration

While it is usually argued that asymmetries, for example in costs,[3], make collusion harder to maintain (Ivaldi et al., 2003; Feuerstein, 2005b), Guigou and de Lamirande (2015) demonstrate that this is not necessarily the case when asymmetry arises from the type of executive compensation. Using the balanced temptation approach by Friedman (1971), they show that in the case of RPE contracts, the effect is ambiguous and depends on the degree of asymmetry. According to their model, a manager who is incentivised by a contract with a lower γ (in our case, this is the manager with an APE contract) may allow the manager under an RPE contract to capture a larger market share to ensure his cooperation in joint profit-maximisation. Intuitively, this arrangement increases the critical discount factor for the APE manager (since he gains *less* from a collusive agreement) but decreases δ for the RPE manager (as a larger market share improves benefits

[2]Note, that this punishment strategy is not optimal (Abreu, 1988); however, it provides significant simplification and improved tractability. For a discussion, see Kuhn (2005) and Feuerstein (2005a). Matsumura and Matsushima (2012) provide a model with optimal punishment in our setting.

[3]For cost asymmetry, for example, firms can achieve joint profit maximisation only when side payments are allowed (Bain, 1948).

from cartelisation). Formally, firms' quantities still add up to a monopoly output under collusion; however, the market is not split equally. The manager with an RPE bonus produces a larger share (s) of the output. It can then be shown that for any market split $(s, 1-s)$, managers under asymmetric contract allocation would have the following values for δ^*_{RPE} and δ^*_{APE}:

$$\delta^*_{APE} = \frac{(4\gamma+3)^2 s^2}{(4\gamma s - 12\gamma + 3s - 10)(4\gamma s - 4\gamma + 3s - 2)} \tag{3.7}$$

$$\delta^*_{RPE} = \frac{(4\gamma+3)^2(2\gamma+1)(s-1)^2}{(8\gamma^2 s + 4\gamma^2 + 10\gamma s + 12\gamma + 3s + 7)(4\gamma s - 2\gamma + 3s - 1)} \tag{3.8}$$

In their analysis, Guigou and de Lamirande (2015) demonstrate that the value of s that minimises $max[\delta^*_{RPE}, \delta^*_{APE}]$ is equal to

$$s^* = \frac{2\gamma+1}{3\gamma+2}$$

This results in the following minimum critical discount factor sufficient for the collusion under asymmetric contract allocation:

$$\hat{\delta} = \frac{(4\gamma+3)^2}{28\gamma^2 + 44\gamma + 17} \tag{3.9}$$

3.2.4 Stability of Collusive Behaviour

In the literature on the stability of collusive behaviour, a standard approach is to focus on the critical discount factor in infinitely repeated games, and it is assumed that collusive behaviour is less stable when the critical discount factor is relatively high. In other words, the higher it is, the more "difficult" collusive behaviour is (Fonseca et al., 2018). Several experimental studies have supported this claim empirically (albeit in a simplified environment). An experimental study by Feinberg and Husted (1993) uses a 2x2 version of the Cournot market as a repeated game with a random termination rule. Authors induce collusive equilibria "through the use of demand and cost parameters favouring collusion, experienced subjects, and instructions biased towards avoiding the prisoner's dilemma". They then manipulate the discount rates through the probability of game termination and analyse the implications for market outcomes. Their findings suggest that the proportion of cooperating participants decreases with rising discount factors[4]. However, their methodology implies that collusion is an equilibrium in only one of their treatments. Furthermore, their restrictions on the action space strongly simplify the interactions in a market setting.

[4]Similar results are presented in Dal Bó (2005), who utilises a comparable setting.

These issues are raised in more recent work by Bruttel (2009). Bruttel chooses a different approach and manipulates payoffs in a repeated price-setting duopoly in a way that changes the critical discount factor (δ^*) instead of actual discount rates (δ). She finds that the distance from δ^* to δ can indeed be used as a measure of the relative degree of cartel stability[5].

With this in mind, a comparison of the critical discount factors allows us to conclude which of the combinations of executive remuneration schemes examined in the previous sections are more likely to lead to collusive behaviour. Comparing our results from subsections 3.2.2-3.2.3 yields the following inequality:

$$\frac{9}{17} \quad < \quad \hat{\delta} = \frac{(4\gamma+3)^2}{28\gamma^2+44\gamma+17} \quad < \quad \delta^* = \frac{(2\gamma+3)^2}{4\gamma^2+20\gamma+17} \qquad \forall \quad \gamma > 0 \tag{3.10}$$

This inequality indicates that the stability of collusive behaviour is highest when neither manager is incentivised by the RPE-based bonus, i.e., in the standard Cournot game. Stability is particularly low when both managers are incentivised by the RPE-based bonus, and asymmetric managerial compensation is in the middle range in terms of stability of collusive behaviour.

An alternative perspective on the factors that predict collusive outcomes has recently been put forward. Blonski et al. (2011) and Blonski and Spagnolo (2015) propose that the *standard* derivation of the critical discount factor does not capture the full strategic risk of collusion. More specifically, by looking at an infinitely repeated prisoner's dilemma, the authors construct a cooperation criterion that takes this risk into account - by adding "*the sucker's payoff*" (the payoff one gets when the opponent deviates) into consideration[6]. The underlying logic of their methodology implies that if the sucker's payoff decreases, the strategic risk of maintaining collusion increases. Although Blonski et al. (2011) do not extend their model to more general repeated interactions[7], the intuition behind their approach points in the same direction as inequality 3.10: the sucker's payoff under the RPE contract is smaller than under the APE contract, as any deviation by the opponent decreases one's profit *and* increases the difference in profits, resulting in lower compensation for the non-deviating manager.

Based on the inequality 3.10 and the intuition behind the approach by Blonski and Spagnolo (2015), we can expect that the likelihood of observing collusive behaviour would

[5]It is important to note, that the market environment in Bruttel (2009) is based on Maskin and Tirole (1988), which involves *sequential* decision making in a price-setting duopoly. As discussed in Ghidoni and Suetens (2022), differences in the nature of interactions (simultaneous vs sequential) can have large consequences for behaviour. Thus, results in Bruttel (2009) cannot be easily generalised to a simultaneous quantity-setting duopoly.

[6]A related idea of the *basin of attraction* of a defective strategy can be found in Dal Bó and Fréchette (2011).

[7]As the authors themselves put it, this would require "imposing a lot more structure". However, Blonski and Spagnolo (2015) does include the calculations for a repeated Cournot duopoly.

decrease with the number of managers incentivised by RPE-based bonuses. This statement can be interpreted in two ways, depending on the definition of collusive behaviour. According to the first or "strict" definition of collusive behaviour, the firms form a cartel and produce a market quantity equal to the monopoly quantity, i.e., they maximise joint profits. Based on this definition, we expect RPE-based bonuses to be detrimental to cartelisation, which leads to the first part of our Hypothesis 2.:

Hypothesis 2a *Increasing the number of RPE-based contracts in the market has a negative effect on cartelisation.*

However, the "strict" definition of collusive behaviour does not take into account that managers can also engage in *partial* collusion, i.e., the market quantity does not correspond to the monopoly quantity but is lower than the market quantity of the Cournot-Nash equilibrium in the presence of RPE-based bonuses (see Table 3.2.1). Our theoretical considerations suggest that it is more difficult to sustain even partial collusion when RPE-based premia are present. This is especially true when both managers receive RPE-based bonuses. Moreover, the results of the experimental study by Boente and Galkin (2023) suggest that RPE bonuses promote over-aggressive behaviour. Against this background, we can formulate the second part of our Hypothesis 2:

Hypothesis 2b *Increasing the number of RPE-based contracts in the market has a negative effect on partial collusion.*

The theoretical derivation of Hypotheses 2a and 2b provides further justification for our Hypothesis 1, which was derived on the basis of the static game. Market quantities increase with the number of managers incentivised by RPE-based bonuses, even in repeated games, as collusion is more difficult to maintain in the presence of RPE-based bonuses.

3.2.5 Implicit and Explicit Collusion

There are basically two ways in which collusive behaviour between companies can come about and our analysis thus far has not differentiated between these two types of collusive behaviour: First, there may be cartel agreements between firms in which the firms' managers *explicitly* communicate their intended behaviour to each other. Second, there can also be *implicit* agreements without any explicit communication. In practice, the focus of antitrust authorities is on preventing explicit collusion. Since explicit collusion cannot be enforced, standard game theory would suggest that the set of equilibria in a repeated oligopoly should be the same whether or not the managers of the two firms can communicate with each other (Fonseca and Normann, 2012). Hence, whether the possibility of explicit communication exists should not be relevant to our hypotheses. However, overwhelming empirical findings going back to Friedman (1967) indicate that communication significantly improves coordination and cooperation rates[8]. A potential mechanism to explain this phenomenon is presented by Dvorak and Fehrler (2020) and Kartal and Müller (2021): communication reduces (but does not eliminate) the strategic risk of cooperation.

Applying this intuition to our market environment, we expect that the ability to communicate would allow managers to make explicit agreements that lower strategic risk, making it more likely that the quantities chosen will increase profits for both firms. This leads to our third hypothesis.

Hypothesis 3 *The possibility of communication between managers favours collusion.*

We expect Hypotheses 1-2b to hold even if managers are able to communicate and thus make explicit agreements. The quantities chosen will be lower, but we still expect RPE-based compensation to make collusive behaviour less likely. A comparison of the critical discount factors (Eq. 3.10) shows that the incentive to deviate is higher for RPE-based compensation than for APE-based compensation. These considerations lead to our final hypothesis.

Hypothesis 4 *The likelihood of deviating from an explicit agreement increases with the number of managers receiving incentives through RPE-based bonuses.*

3.3 Experimental Design

We test the above hypotheses in a lab experiment where participants make repeated choices in a quantity-setting duopoly with a random termination rule. In total, subjects play four supergames, which differ in the type of contract they are compensated with and the type of contract their opponent is compensated with. Thus, we obtain the choices in four possible conditions (APEvAPE, APEvRPE, RPEvAPE, RPEvRPE). We make further distinctions between two environments: one where only tacit collusion is possible (No Communication treatment) and one where participants can make explicit agreements about their strategies before each supergame (Communication treatment).

In the rest of this section, we first outline the specifics of the experimental markets, followed by a more in-depth discussion of our methodological decisions.

3.3.1 Market Setup

The market environment in our experimental setting is built upon the framework outlined in the previous section. We used the parameter values $a = 100$ for the linear inverse demand function, $c = 0$ for the cost and profit functions, and $f = 100, \gamma = 1$ for the compensation schemes. Subjects act as managers of firms and decide what quantity their

[8]See Balliet (2010) for a general survey of literature on cooperation in social dilemmas, and Haan et al. (2009) and Fonseca and Normann (2012) for the effects of communication in the market setting.

respective firms produce. A manager with an APE-based contract receives the following compensation:

$$v_i^{ape} = \begin{cases} \pi_i + 100 & \pi_i > 0 \\ 0 & \text{otherwise} \end{cases} \tag{3.11}$$

In the case of the RPE bonus scheme, the reward of the manager depends on the profits of both firms:

$$v_i^{rpe} = \begin{cases} \pi_i + 100 + (\pi_i - \pi_j) & v_i^{rpe} > 0 \\ 0 & \text{otherwise} \end{cases} \tag{3.12}$$

The Cournot-Nash equilibria for the static game and respective critical minimum discount factors are presented in Table 3.3.1.

Table 3.3.1: Experimental Predictions for the Static Game

	APEvsAPE	**APEvsRPE**	**RPEvsRPE**
Quantities	66 (33, 33)	72 (29, 43)	80 (40, 40)
Profits	2244 (1122,1122)	2028 (812, 1204)	1600 (800, 800)
Compensation	2444 (1222, 1222)	2608 (912, 1696)	1800 (900, 900)
Consumer Surplus	2178	2592	3200
Collusive Quantity	50 (25, 25)	50 (20, 30)	50 (25, 25)
Collusive Compensation	2700 (1350, 1350)	3200 (1100, 2100)	2700 (1350, 1350)
Discount factor (δ)	≈ 0.53	≈ 0.55	≈ 0.61

Notes: Numbers in brackets correspond to the firm-specific outcomes. In the case of the asymmetric market, the first number corresponds to the outcome of the firm with APE-based compensation. The outcomes are rounded to the nearest point.

3.3.2 Methods

Existing experimental literature (Haan et al., 2009) points out that specifics of the design (information availability, past history, possible modes of communication) of experiments in a repeated setting may significantly influence individual decision-making. Overall, our study investigates the effects of RPE-based contracts on the intensity of competition and collusion rates compared to APE-based contracts. Therefore, as long as our specific conditions remain constant across all supergames, we are able to evaluate the causal effect of the RPE bonuses. However, for the sake of completeness and to allow for an adequate comparison of our experiment to previous studies, it is important to highlight certain features of our design along with the insights from existing literature that may have an effect on outcomes of interest.

Treatment I: Absolute Performance Evaluation (APE) versus Relative Performance Evaluation (RPE)

Each subject makes output decisions in four different combinations of managerial compensation:

1. Both managers receive APE-based compensation (symmetric APE market).
2. Both managers receive RPE-based compensation (symmetric RPE market).
3. The subject receives APE-based compensation, while the manager of the other firm receives RPE-based compensation.
4. The subject receives RPE-based compensation, while the manager of the other firm receives APE-based compensation (the last two cases represent asymmetric markets).

Hence, we employ a within-subjects design for this treatment. While within-subject designs potentially suffer from confounds, they have more power than between-subject designs. To control for order effects, the order of the four different combinations is random at the individual level. Moreover, at least for each subject's first combination, we can also perform a between-subjects analysis.

Treatment II: Communication (C) versus No Communication (NC)

The second treatment is related to the distinction between tacit and explicit collusion. To examine the causal effect of RPE-based compensation on managerial decision-making, we allow a sub-sample of our subjects to communicate before each supergame. In contrast, the other subjects do not have this option. In other words, by allowing subjects to communicate, we enable them to reach explicit agreements, whereas, without the opportunity to communicate, only tacit agreements are possible at best. Existing experimental studies suggest that for oligopoly markets, once the cooperative agreement has been established, the firms would continue to collude even when communication is disabled (Fonseca and Normann, 2012). The communication page contained a chat window and a profit calculator to help participants with their decisions. We have limited the chat duration to three and a half minutes without any restrictions. Although this design choice makes the analyses of agreed-upon quantities somewhat more cumbersome, the free-form communication is significantly more effective in establishing collusion (see Waichman et al. (2010), Cooper and Kühn (2016) and Brandts et al. (2019) for additional literature review). Subjects also had the option of skipping this page altogether. The possibility of communication thus allows explicit collusion, but the subjects can also deliberately refrain from communication. For this treatment, we use a between-subjects design in which subjects are randomly assigned to either the group of subjects in which the two managers cannot communicate or the group of subjects in which the two managers can use chat to communicate.

Infinitely Repeated Games

Our theoretical framework outlined in section 3.2 implies that market decisions are made under the assumption of an infinite horizon. The standard approach for running infinitely repeated games in economic experiments is based on a random termination procedure as proposed by Roth and Murnighan (1978). In other words, subjects play *indefinitely* repeated games that end in a finite time, with the exact time of the end unknown to the players. They only know that the game ends after each period with a certain probability. Theoretically, infinitely repeated games with payoff discounting are isomorphic to indefinitely repeated games without payoff discounting. However, as noted by Fréchette and Yuksel (2016), these environments may differ in practice. From the perspective of our setting, the framing of random termination makes sense, as managerial contracts may end prematurely and unexpectedly (Kaplan and Minton, 2011), and companies may leave the market or be acquired. However, using the random termination method can result in a significant variation in the number of periods played.

Thus, we employ a variation of a block random termination procedure proposed by Fréchette and Yuksel (2016). We use a probability of stopping of $p = 10\%$ (the expected length of a supergame is ten periods). According to the block random termination approach, the state of the market is only revealed after the subjects have played a minimum number of periods (10). If the market ends before period 10, only the periods up to the "last" period are relevant for the payoffs, and all other decisions within the first 10 periods are irrelevant for the subjects' payoffs. Subjects are provided with this information, along with some examples, during the introduction stage (see Appendix 3.C - Experimental Instructions). This method implies that we can use the first ten periods of each market in our statistical analyses. Furthermore, we have randomised the supergame duration before the experiment to ensure a reasonable session duration. The resulting supergames lasted for [11,8,13,9] periods and were fixed throughout the sessions. Finally, our chosen continuation probability ($p = 90\%$) ensures that collusion can be theoretically sustained under all possible contract combinations.

Upon completion of the experiment, subjects were paid a cumulative amount for the payoff-relevant periods in one randomly chosen supergame. This payment method is consistent with preferences assumed by the framework of the infinite-horizon games with discounting (Sherstyuk et al., 2012).

Instructions

The instruction stage of the experiment contained contextual instructions with regards to the framing of the environment, for example, referring to “firms”, “managers”, “product”, “compensation”, and “contracts”. In a review of the experimental literature, Alekseev et al. (2017) conclude that meaningful language is either useful or does not change behaviour in the vast majority of cases. Furthermore, the instructions did not use any language that may induce aggressive behaviour (for example, referring to the matched participant as “the other person” and not as “opponent” or “rival”). Throughout the experiment, APE contract was described as “contract A”, and RPE contract was described as “contract B”. As the experiment was conducted in German, we also avoided the use of any gendered references (e.g., using the words “person” or “management”). Appendix 3.C provides the complete instructions, translations and page layouts.

We provided subjects with a profit calculator[9] for ease and efficiency, enabling them to quickly determine firm profits based on output quantities. When a subject changed the position of the slider (and thus the output quantity) for either firm, they could immediately see the resulting profits of the two firms. During the learning and introduction stage, the calculator also displayed the resulting compensation from the profits for both types of contracts. The outcomes are rounded to the nearest point as in Table 3.3.1. As explored by Mason and Phillips (1997), full information about the possible payoffs improves cooperation rates, which we also expect to be true in our setting. However, only the compensation for the current contract was shown during the decision stages.

To confirm that participants understand the market environment and the functionality of the sliders, we provided them with three control questions concerning potential scenarios under the given market conditions. These questions were the same for all participants and could only be solved using the calculator. Participants were only permitted to continue once they answered all questions accurately.

Information

Throughout the decision stages, participants also received information about which contract they were assigned and which contract was assigned to their opponent. This design choice was implemented for two reasons. First, the complete information provision reduces the complexity of participants’ decisions as they do not have to form expectations about possible contracts of the rival manager. Second, in most countries, publicly traded companies are obliged to report the details of the remuneration packages for executive managers, making our framing more realistic.

However, the participants knew neither the order of contracts they would play nor the

[9]Requate and Waichman (2011) establish that there is no significant difference in experimental results in duopoly market games between a payoff calculator and a payoff table.

contracts their next opponent would be playing. Since the contract order may influence the behaviour in subsequent games (for example, Huck et al. (2001) report "aspiration levels", which changes the behaviour depending on the order of play), we balanced the possible contract combinations[10].

The last important aspect of information availability is concerned with the feedback participants receive during repeated play. Throughout the decision stages, participants in our experiment received information about the past actions of the rival, the profits of both firms, and their resulting compensation (but not the compensation of the rival manager). Our choice of this environment is aimed to make the setting more realistic, as it is natural to assume firms (and, thus, managers) to gather all available information about the historical developments in the market (Haan et al., 2009). The theoretical approach by Vega-Redondo (1997)[11] suggests that providing profits of competing firms would drive the Cournot market towards a Walrasian equilibrium. Huck et al. (2000) provide some evidence supporting Vega-Redondo's conjecture. However, these results are challenged by Bru et al. (2002)[12], who provide the entire history of actions (in contrast, Huck et al. (2000) only provide the outcomes of the previous period) and find more collusive outcomes in their environment. Furthermore, a recent metastudy (Fiala and Suetens, 2017) finds that transparency about the actions of the opponents tends to lead to higher cooperation rates. Against this background, we would expect our method of presenting past history of play to positively affect the likelihood of observing collusive behaviour.

Experimental Flow

Our experimental flow can be summarised in the following way:

1. **Introduction Stage:**
   Participants get information about the market environment, their compensation under **both** possible contracts (APE and RPE) and rules about the duration of the market. They are also given a tool to help them with their decisions: a calculator that outputs the resulting profits and their compensation given the outputs of their firm and the output of the other firm in a duopoly.

2. **Practice Stage:**

[10]Thus, out of the group of 16 participants, four would have their first supergame in the symmetric APE market, four would start in the asymmetric market with APE contract, four would start in the asymmetric market with RPE contract, and four would start in the symmetric RPE market. For the next supergame, each participant would play a different market setting while the total distribution of the contract allocations remained constant.

[11]This evolutionary framework is built on the idea that a firm imitates the behaviour of the most profitable rival and, with a small probability, (mistakenly) chooses some arbitrary output.

[12]Some other evidence is presented, for example, by Offerman et al. (1997). See Haan et al. (2009) for a more general discussion.

Participants are given time to familiarise themselves with a calculator and play a practice game where they can choose quantities for both firms and see the resulting compensation.

3. **Matching Stage:**
   Participants are assigned a contract and are randomly matched to another participant in a session.

4. **Communication Stage:**
   If the participants are in the "Communication" treatment, they are allowed to coordinate their strategy before a supergame. The chat is limited to three and a half minutes.
   In the "No Communication" treatment, participants only get information about their contact and the contract of the opponent.

5. **Decision Rounds**:
   Participants make simultaneous quantity choices for each period until the supergame ends. Throughout the duration of the supergame, the matching remains fixed.

6. **Rematching:**
   After the supergame ends, participants are rematched with a new participant (stranger matching) and steps 3-5 are repeated. Each participant plays four supergames in total.

7. **Payment:**
   After the decision stages conclude, a random draw decides which supergame is payoff-relevant, and the participant receives the cumulative compensation for the respective supergame.

3.3.3 Sample

The experiment consisted of seven sessions, which took place at the DICElab of Heinrich Heine University Dusseldorf (four sessions) and the EconLab of the University of Wuppertal (three sessions) in June 2023. A total of 96 participants took part in the experiment. Each session consisted of either 8 or 16 subjects to ensure the balanced allocation of contract combinations. The experiment has been programmed in oTree (Chen et al., 2016), and participants were recruited via ORSEE (Greiner (2015), EconLab) and hroot (Bock et al. (2014), DICELab). The sessions lasted, on average, 60 minutes both for Chat and Implicit Collusion treatments. The experimental sample predominantly consisted of students (98 per cent) of various backgrounds. Table 3.A.1 (Appendix 3.A) provides complete demographic information about our sample.

Participants received a show-up fee of 6 Euro (DICELab) and 5 Euro (EconLab) plus the cumulative compensation based on their decisions in the experiment. We used

"Experimental Points" (EP) as currency, with 1000 EP = 1 Euro. Subjects earned from 7.30 Euro to 30.5 Euro, with an average payment of 15.4 in the "No Communication" treatment and 20.4 in the "Communication" treatment.

3.4 Experimental Results

We now turn to the experimental results. As already stated in the introduction, we are primarily interested in three questions: whether RPE contracts enhance efficiency (Hyp. 1), if they act as a deterrent to tacit collusion (Hyp. 2a-2b), and if their impact is potent enough to disrupt explicit agreements (Hyp. 4). Additionally, we are interested in the "level" effect of communication (Hyp. 3). For the reader's convenience, we first provide descriptive statistics and visualisation of our findings for both treatments. We then turn to more formal tests of the hypotheses outlined in section 3.2[13].

3.4.1 First look at the Data

Table 3.4.1 reports the average observed quantities for three different combinations of managerial compensation schemes that vary in the number of managers incentivised by RPE-based bonuses (APE vs APE (0), APE vs RPE (1), and RPE vs RPE (2)). Results are reported separately for subjects who were able to communicate with the other firm's manager (C) and subjects who were unable to do so (NC, no communication). As can be seen from the table, our results provide preliminary evidence for Hypothesis 1, as the average market quantities increase with the number of managers incentivised by RPE-based bonuses. However, for all three bonus combinations, the consumer surpluses are remarkably lower in the C-treatment than in the NC-treatment, and the positive impact of RPE-based bonuses is lower in the C-treatment, where the increases in consumer surplus from symmetric APE to symmetric RPE is about 20 per cent, while the increase is around 30 per cent in the NC-treatment.

In our experimental setup, the collusive market quantity maximising joint profits is 50 (see Table 3.3.1). According to our strict definition of collusive behaviour, firms would, therefore, form a *cartel* only if the observed market quantity is exactly equal to the monopoly quantity of 50. However, it is likely to be difficult, especially in the NC treatment, for this exact market quantity to arise from the individual decisions of the subjects. Therefore, we call a cartel market if the observed quantity is less than 52. The results in Table 3.4.1 show that the share of cartel markets in the NC treatment is lower (9.6 per cent) in the symmetric RPE case than in the symmetric APE case. In the C treatment, the share of cartel markets is also lower (64 per cent) in the symmetric RPE case than in the symmetric APE case, although only slightly. Moreover, the effect of the number of managers with RPE-based bonuses on cartelisation is not monotonic, as the share of cartels is higher (C-treatment) or lower (NC-treatment) in the asymmetric case

[13]Based on the current data.

than in the symmetric RPE case. Hence, Hypothesis 2a is not clearly supported by our results. However, the positive effects of the C-treatment are clearly present as the share of cartel markets increases considerably: in symmetric APE, the share of cartel markets is 12 per cent in the NC-treatment but 69 per cent in the C-treatment. Hypothesis 3 is clearly supported by this data. The results of our experiment suggest that the possibility of explicit collusion leads to a reduction in allocative efficiency.

	No Communication (NC)				Communication (C)			
Market Type	N	Share of cartels	Quantity	Consumer Surplus	N	Share of cartels	Quantity	Consumer Surplus
APE v APE	280	0.12 (n=34)	68.06 (0.81)	2383.51 (55.34)	200	0.69 (n=138)	54.94 (0.7)	1557.9 (46.27)
APE v RPE	560	0.05 (n=28)	74.27 (0.61)	2782.43 (39.22)	400	0.72 (n=289)	55.03 (0.59)	1575.41 (38.29)
RPE v RPE	280	0.096 (n=27)	77.94 (0.92)	3107.89 (64.55)	200	0.64 (n=128)	59.45 (1.07)	1871.98 (73.31)

Notes: Numbers in brackets correspond to the standard errors of the mean unless otherwise specified.

Table 3.4.1: Observed Market Outcomes

We illustrate our findings in Figure 3.4.1, which shows the average observed market quantities for the first ten periods of the supergames. The dashed lines show the Cournot-Nash equilibrium quantities for each combination of compensation schemes (symmetric APE, symmetric RPE, and asymmetric compensation) and the market quantity that maximizes joint profits (see Table 3.3.1). In the graphical illustration, the results for the C and NC treatments are again shown separately.

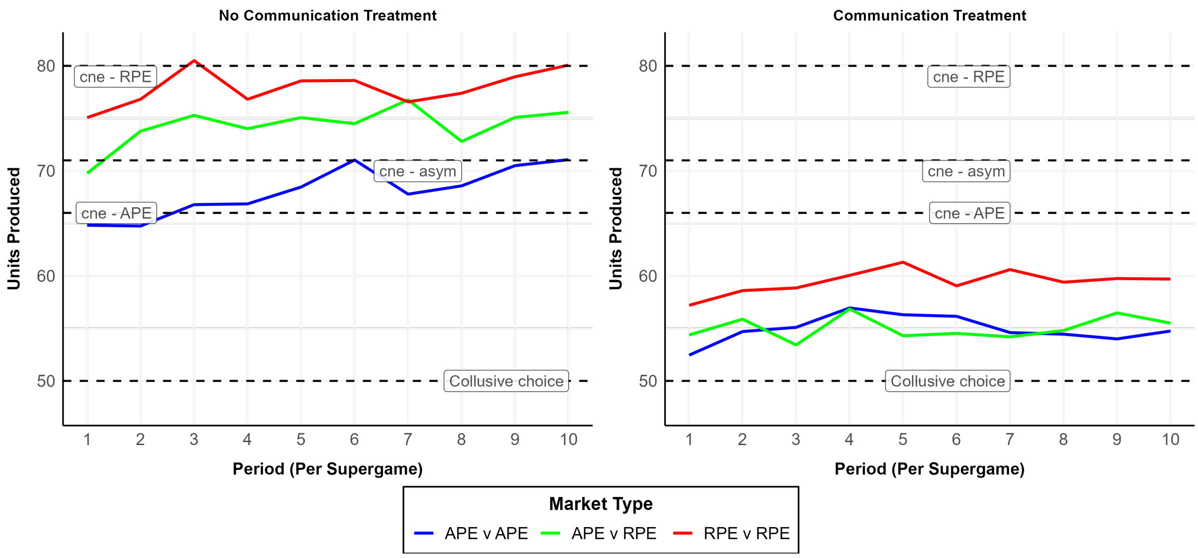


Figure 3.4.1: Average Observed Market Quantities for Different Combinations of Bonus Schemes and for C and NC Treatment

The left graph shows the results of the NC treatment. As theoretically predicted, market quantities increase with the number of managers receiving RPE-based bonuses. Hence, Figure 3.4.1 provides additional visual support for our Hypothesis 1. We can also deduce that in markets with symmetric RPE, market quantities generally fall below the Cournot-Nash equilibrium quantity. In contrast, average market quantities are above the Cournot-Nash equilibrium quantities in situations with symmetric APE or when bonuses are asymmetric. Moreover, the average quantities chosen by the subjects are always far above the quantity that would result from collusive behaviour. Although this holds for symmetric APE cases, notably high market quantities are especially evident in the context of symmetric RPE. Since RPE-based bonuses lead to higher market quantities, they improve the allocative efficiency of markets. The right plot shows the results for the C treatment, where participants can explicitly collude. We again find that markets with symmetric RPE bonuses tend to lead to higher market quantities than markets with symmetric APE or asymmetric compensation. Thus, allocative efficiency is highest when both managers receive RPE-based bonuses. The causal effect of the C treatment is very clear, as the observed market quantities are now much lower than the Cournot-Nash equilibrium quantities and closer to the market quantity that results when managers behave collusively.

However, comparing markets with different combinations of bonus schemes is not without problems, as these markets differ with regard to their Nash Equilibria. To graphically illustrate the link between combinations of bonus schemes under C and NC treatment, we therefore look at the Collusion Index (CI) that has been used, for example, by Suetens and Potters (2007) and Anderson et al. (2014):

$$\rho_t = \frac{\bar{Q}_t - Q_{Nash}}{Q_{JPM} - Q_{Nash}}$$

where $\bar{Q}_t$ is the observed market quantity, Q_{Nash} is the Nash equilibrium, Q_{JPM} is the joint profit-maximising quantity. Markets closer to the cartel outcome would have a larger collusion index (with $\rho = 1$ being a perfect cartel), and any collusion index above 0 would imply that markets achieved at least some level of cooperation relative to the respective Nash equilibrium. Figure 3.4.2 presents the density graphs of the observed collusion indices for each allocation of compensation schemes, along with the median (dashed vertical line) and the mean (solid vertical line).

The first point worth noting is that the median collusion index for each market in the NC treatment is very close to the respective Nash equilibrium ($\rho = 0$), while in the C-treatment, the majority of the markets have achieved perfect collusion ($\rho = 1$). This observation is in line with our Hypothesis 3, as we hypothesised that the possibility of communication between managers favours collusion. According to the Hypothesis 2b, we would also expect the density graphs to have more weight on the negative ρ in the markets with RPE-based compensation, particularly in the NC treatment. Figure 3.4.2

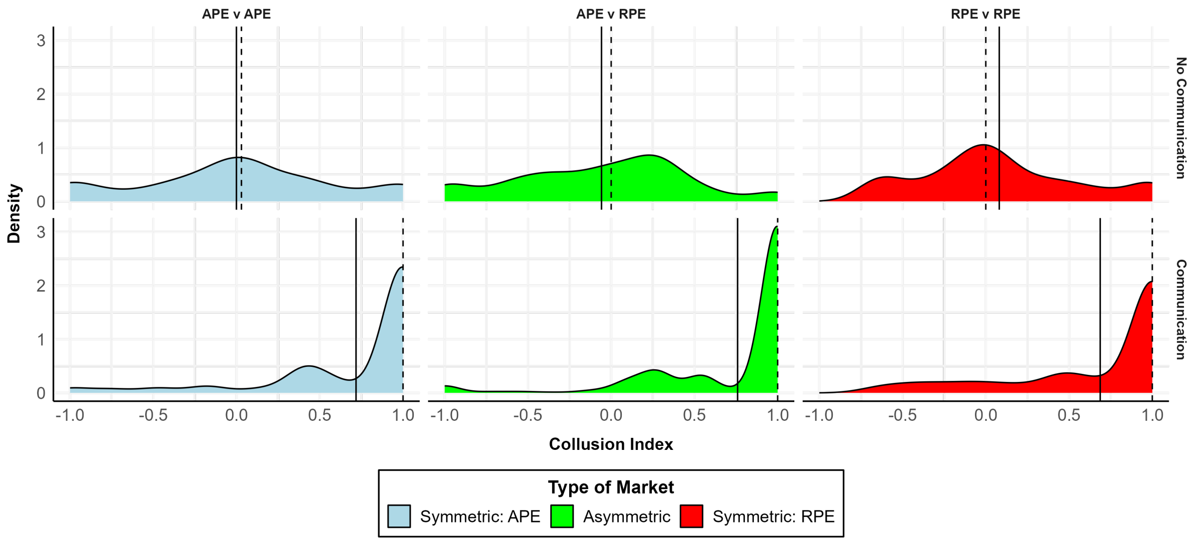


Figure 3.4.2: Density of Observed Collusion Indices

does not support this conjecture. Thus, we can conclude that the allocative efficiency gains, evident in the average observed quantity graph (Fig. 3.4.1), can be attributed to the theoretically predicted outcomes of the static game.

Figure 3.4.3 illustrates the share of *cartel* markets for each of the first ten periods of the supergames. The left plot shows the results for the NC treatment, and the right plot shows the results for the C treatment. The comparison of the two graphs indicates the apparent causal effect of communication ability on the proportion of collusive markets. This is a direct confirmation of Hypothesis 3, as significantly more markets have achieved cartel outcomes under explicit collusion treatment. In contrast, Figure 3.4.3 does not support Hypothesis 2a, as the proportion of markets with joint profit maximising quantities does not clearly increase with the number of managers incentivised by RPE-based bonuses.

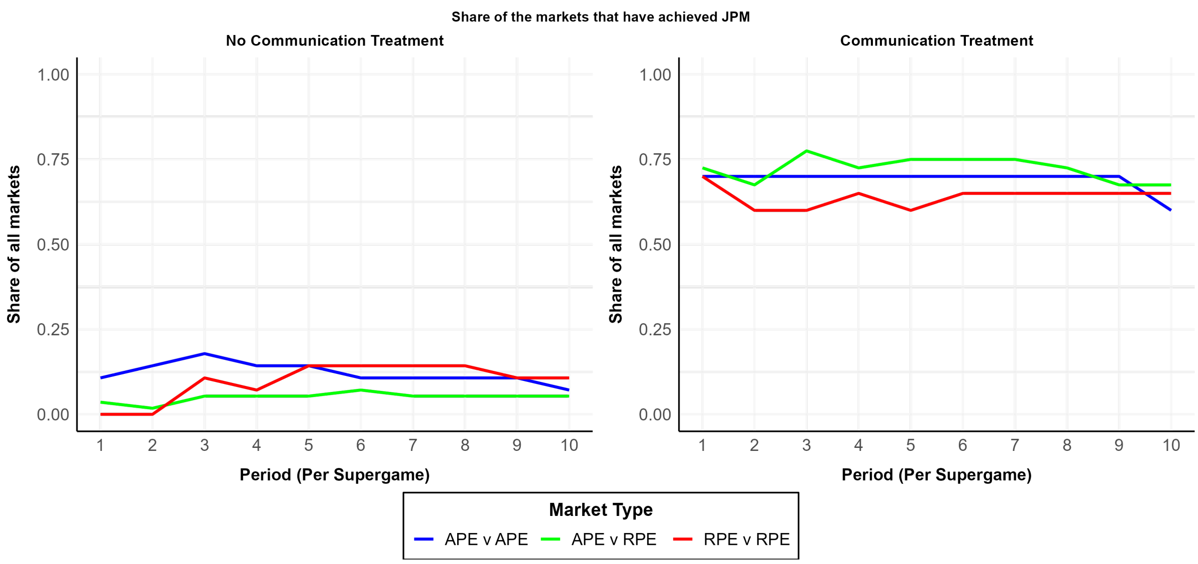


Figure 3.4.3: Share of the Markets that Achieved Joint Profit Maximisation

According to Hypothesis 2b, we expect the proportion of markets in which *partial* collusion is achieved to decrease with the number of managers receiving RPE-based bonuses. Figure 3.4.4 shows the proportion of markets where the observed market quantities are lower than the Cournot-Nash equilibrium (partial collusion). Again, a clear causal effect of the C-treatment is observed, as the proportion of partially collusive markets increases substantially in the presence of the communication option. In contrast, RPE-based bonuses do not seem to systematically affect partial collusion.

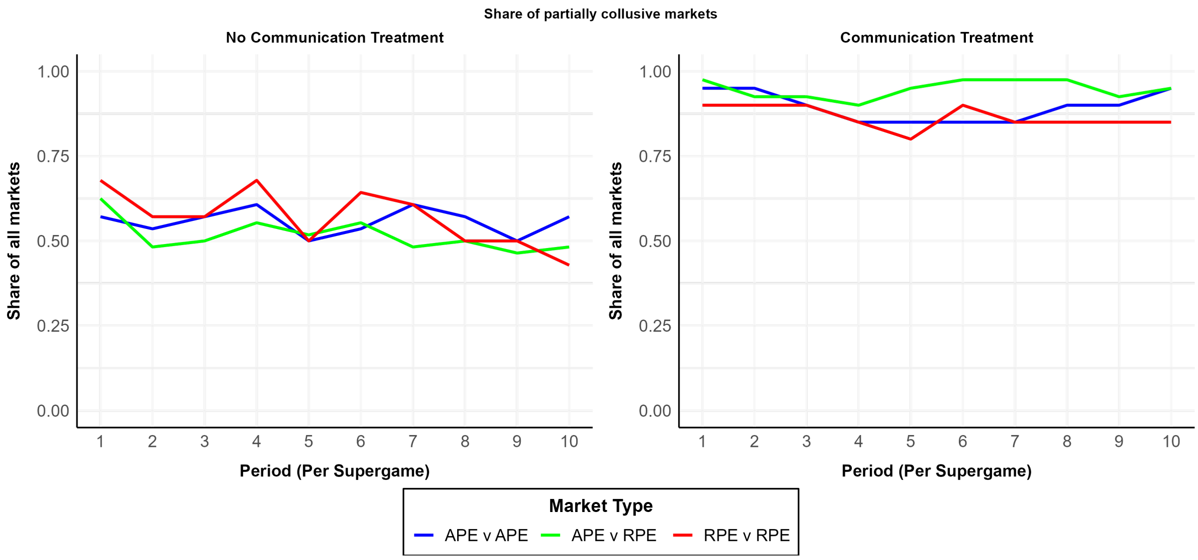


Figure 3.4.4: Share of Partially Collusive Markets

3.4.2 Hypothesis Testing

We now turn to formal tests of our hypotheses, a statement of results, and the analysis of explicit communication agreements.

Observed Market Quantities (Hypothesis 1)

We first evaluate the average market outcomes. According to Hypothesis 1, the average observed market quantities increase with the number of managers incentivised by RPE-based bonuses. Thus, RPE-based bonuses improve allocative efficiency (i.e., result in a larger consumer surplus) through elevated quantity choices. Figure 3.4.1 and Table 3.4.1 provide strong evidence that, at least in the NC treatment, both quantities and consumer surplus increase with the number of managers incentivised by RPE-based bonuses. We supplement these findings by running the Jonckheere-Terpstra test for ordered ascending alternatives ($p < 0.0001$). For the Communication treatment, these effects are weaker. Non-parametric tests show a statistically insignificant effect for the Communication treatment (Jonckheere-Terpstra test: $p > 0.08$). As an additional test, we run a series of regressions of the form:

$$Y_{ij} = \beta_0 + \beta_1 RPE_{ij} + \beta_2 C_i + \beta_3 C_i \times RPE_{ij} + Controls + e_{ij} \tag{3.13}$$

where Y_{ij} is the observed quantity in a matched market i in round j, RPE_{ij} is the number of managers in the market who are incentivised by RPE-based bonuses, and C_i is a dichotomous variable taking the value of one if the market was in C-treatment. We control for possible learning effects for periods within a supergame ($Period_j$) and between supergames ($Supergame_j$). Similar to the methodology in Chapter 2, we account for the potential autocorrelation by employing robust standard errors clustered at the matched market level[14]. Table 3.4.2 Models 1-6 present the estimates of resulting regressions with and without controls for NC treatment (Models 1-2), C treatment (Models 3-4) and the pooled sample (Models 5-6).

Table 3.4.2: Regression Analysis - Observed Quantities

Subsample:	No Communication (NC)		Communication (C)		Pooled	
Model	1	2	3	4	5	6
Intercept	68.70***	64.76***	53.86***	59.09***	68.70***	68.58***
	(1.75)	(2.75)	(1.91)	(2.93)	(1.75)	(2.48)
RPE	4.94**	4.94***	2.25	2.25	4.94**	4.94**
	(1.51)	(1.49)	(1.91)	(1.77)	(1.51)	(1.51)
C					−14.83***	−14.83***
					(2.59)	(2.54)
$C \times RPE$					−2.68	−2.69
					(2.43)	(2.37)
Num.Obs.	1120	1120	800	800	1920	1920
Controls		✓		✓		✓
R2 Marg.	0.055	0.073	0.016	0.119	0.307	0.323
R2 Cond.	0.576	0.593	0.764	0.771	0.739	0.745

Notes: Significance levels at * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Cluster-robust standard errors are in parentheses.

Table 3.4.2 Models 1-2 show that each additional RPE contract significantly increases the observed quantities in the No Communication treatment. When communication is possible (Models 3-4), the effects are present but are smaller and are not statistically significant. In the pooled regressions (Models 5-6), the coefficient of the interaction term, β_3, is negative, yet not statistically different from 0. Put differently, the data does not allow us to definitely rule out the effects of RPE contracts when explicit agreements are allowed. Rather, the evidence suggests that, in such contexts, these effects are less pronounced.

Regression in Eq. 3.13 assumes that the effects of each additional RPE bonus present in the market are linear. We conduct two alternative regression analyses to supplement this initial approach. The first specification employs a factor variable to represent each possible contract allocation. The second specification utilises a dichotomous variable to

[14]See Oshchepkov and Shirokanova (2020) and Pustejovsky and Tipton (2017) for a discussion.

indicate the presence or absence of RPE contracts. Tables 3.A.2-3.A.3 (Appendix 3.A) present the findings, which are broadly in line with the previous conclusions. Thus, we report:

Result 1 *When only tacit collusion is possible, the presence of managers incentivised by RPE-based bonuses leads to a statistically significant increase in observed market quantities. When managers can communicate, the effect of RPE-based bonuses is not statistically significant.*

Cartel markets (Hypothesis 2a)

As is evident from Table 3.4.1 and Figure 3.4.3, we observe some decrease in the share of cartels in the NC treatment, but, contrary to our Hypothesis 2a, the largest drop in the rate of cartel formation happens in the asymmetric market setting. Results from the C treatment do not show a large difference between the symmetric APE market and the market with asymmetric bonuses. However, we find a small decrease in the rate of cartel formation for the markets with two RPE contracts.

We assess the statistical significance of these findings by running a mixed model logistic regression and a linear probability model (Table 3.4.3 - Models 1-2). As a dependent variable, we use the probability of the market being a *cartel*. We account for possible correlations in our data by including a random intercept on the group level (Gelman and Hill, 2006) and for possible learning effects by including the respective periods and supergames[15]. Although the effects of RPE contracts are still present in both models, only the effect of communication is significant. Therefore, our data implies the following:

Result 2 *RPE contracts do not have statistically significant effects on the rates of cartel formation.*

Partially collusive markets (Hypothesis 2b)

While Hypothesis 2a focuses on a “strict” view of cartels, Hypothesis 2b looks into the likelihood of observing at least some degree of cooperation. Intuitively, if the participants are able to achieve a market outcome below the respective Nash equilibrium, their market is partially collusive. According to the Hypothesis 2b, we would expect managers with RPE contracts to be more competitive (i.e., engage in “quantity wars”), resulting in a lower proportion of the partially collusive markets. Figure 3.4.4 suggests that the share of partially collusive markets is stable across different contract allocations throughout the duration of each supergame. Figure 3.4.2 presents similar conclusions, as the median collusion index is close to 0. The regression analysis further supports this conclusion (Table 3.4.3 - Models 3-4). Thus:

[15]Regressions were run with lme4 package in R (Bates et al., 2011).

Result 3 *RPE contracts do not have statistically significant effects on the rates of partial collusion.*

Table 3.4.3: Generalised Linear Mixed Models and Linear Probability Models: Cartels and Partial Collusion

Dependent Variable	Pr(Cartel)	Pr(Cartel)	Pr(Part. Coll.)	Pr(Part. Coll.)
Model	1	2	3	4
Type	GLMM‡	LPM†	GLMM‡	LPM†
Intercept	−13.09***	−0.08	0.21	0.54***
	(2.46)	(0.07)	(0.77)	(0.08)
RPE	−0.29	−0.01	0.00	0.01
	(1.29)	(0.03)	(0.42)	(0.05)
C	20.03***	0.63***	5.35***	0.39***
	(2.43)	(0.09)	(0.96)	(0.08)
$C \times RPE$	0.32	−0.01	−0.33	−0.02
	(1.71)	(0.08)	(0.74)	(0.06)
Num.Obs.	1920	1920	1920	1920
Controls	✓	✓	✓	✓
R2 Marg.	0.359	0.439	0.346	0.164
R2 Cond.	0.988		0.818	

Notes: Significance levels at * p < 0.05, ** p < 0.01, *** p < 0.001. Presented regressions are of the following form: $Y_{ij} = \beta_0 + \beta_1 RPE_{ij} + \beta_2 C_i + \beta_3 C_i \times RPE_{ij} + Controls + \eta_i$. Except for the dependent variable Y_{ij}, the notation is the same as in Eq. 3.13. ‡Generalised linear mixed models: Dependent Variable $Logit(Pr(Y_{ij} = 1))$, where Y_{ij} is a variable taking the value 1 if the observed market i in period j is a Cartel (Partially Collusive). Coefficients are in log-odds for intercept and log-odds ratios for predictors.†Linear probability models: Dependent variable $Pr(Y_{ij} = 1)$. Regressions are estimated with an OLS approach. Coefficients are in the marginal probabilities. Cluster-robust standard errors (for LPMs) are in parentheses.

Effects of Communication (Hypothesis 3)

As expected, explicit communication strongly affects all outcome variables we are interested in. Figures 3.4.1-3.4.2 and Table 3.4.1 provide prima facie support that communication increases the likelihood of cartelisation and lowers observed quantities and social welfare. These effects are statistically significant in all of our model specifications (Tables 3.4.2 - 3.4.3). The possibility of forming explicit agreements dampens the pro-competitive effects of RPE-based compensation to the point where they are no longer statistically significant.

Result 4 *Communication increases cartelisation rates and decreases observed quantities independent of the type of managers' compensation.*

Explicit Collusion (Hypothesis 4)

As is evident from the tests of Hypothesis 3, explicit agreements are problematic from the welfare perspective. According to Hypothesis 4, we would expect that managers under

RPE would have a larger incentive to deviate and break these agreements. The analysis of the cartelisation rate (Hyp. 2a) may not capture the full extent of these deviations as managers may agree on the quantities that are not joint-profit-maximising (or partially collusive). Since the communication data is perfectly observable, we can identify the agreed-upon levels of production and compare them with the actual choices. As we focus specifically on explicit agreements, we exclude all markets where the agreement has not been reached (for example, some participants skipped the communication step either due to impatience or technical reasons). Lastly, we exclude all markets where participants have agreed to play an Alternating Monopoly[16]. Table 3.4.4 presents individual decisions in every possible contract allocation.

Market Type	N (Total Observations)	N (Deviation)	Proportion of Deviations	Average Period of Deviation	Average Size of Deviation
APEvAPE	320	11	0.03	6.27	12.91
APEvRPE	280	17	0.06	6.71	11.53
RPEvAPE	280	17	0.06	6.65	12.06
RPEvRPE	280	37	0.13	5.95	13.54

Table 3.4.4: Explicit Agreements and Deviation Analysis

Table 3.4.4 provides suggestive evidence that RPE contracts may undermine explicit agreements. Specifically, the proportion of individual choices, different from agreed-upon quantities, doubles for each additional RPE contract in the market. These trends in deviation rates across each supergame are further depicted in Figure 3.4.5. While the overall deviation rates are relatively low, individual decisions in the markets where both managers have RPE contracts show a consistently higher likelihood of breaking explicit agreements.

We access the statistical significance of these observations by running logistic regressions of the form:

$$Logit(Pr(Y_{ij} = 1)) = \alpha_{0,1,2,3} \times MarketType_{ij} + Controls \tag{3.14}$$

Where Y_{ij} is a dichotomous variable taking the value of one if the participant i has deviated from the collusive agreement in the period j, $MarketType_{ij}$ is a factor variable with four levels (i.e., APEvAPE, APEvRPE, RPEvAPE, RPEvRPE), indicating the contracts present in the market when the decision has been made. We control for possible learning effects for periods within a supergame ($Period_j$) and between supergames

[16]Alternating monopoly is a strategy where participants alternate between monopoly output and no output. In a standard Cournot, this strategy generates the same outcome as a perfect cartel. RPE-based bonuses provide additional incentives to engage in such behaviour since RPE compensation is bounded from below. This issue is not covered in the theoretical section, primarily due to its implausibility in real markets. We go into further detail about this potential flaw in our design, its implication for the strategy and a simple fix in Appendix 3.B.

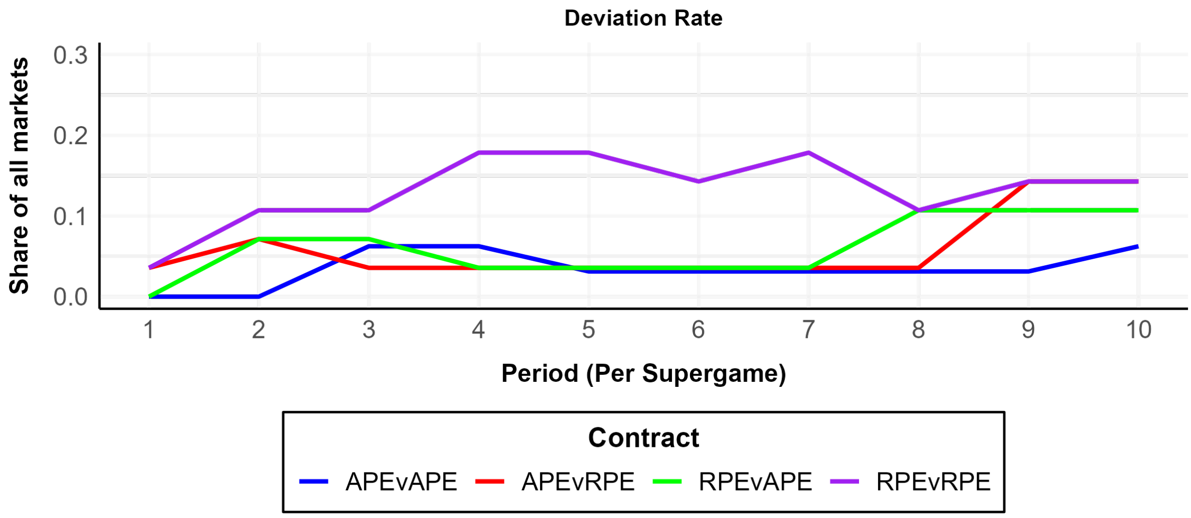


Figure 3.4.5: Devitiations from Collusive Agreements

($Supergame_j$). Since participants make repeated decisions in our setting, we also run a Generalised linear mixed model with a random intercept on the participant level as a robustness check[17]. We supplement our analysis with linear probability models with errors clustered at the individual level for the convenience of the reader. Table 3.4.5 presents our findings.

Table 3.4.5: Regression table: Deviations from Collusive Agreements

Model	GLM 1	GLM 2	GLMM 1	GLMM 2	LPM 1	LPM 2
Intercept	−3.34***	−3.85***	−7.98***	−9.15***	0.03	0.11**
	(0.31)	(0.79)	(1.96)	(1.41)	(0.02)	(0.04)
APEvRPE	0.60	0.83*	1.81**	1.98*	0.03	0.04
	(0.40)	(0.42)	(0.59)	(0.88)	(0.04)	(0.04)
RPEvAPE	0.60	0.83*	1.49**	3.20***	0.03	0.04
	(0.40)	(0.42)	(0.57)	(0.87)	(0.04)	(0.04)
RPEvRPE	1.45***	1.49***	2.71***	2.44**	0.10	0.09
	(0.35)	(0.38)	(0.58)	(0.90)	(0.06)	(0.05)
Num.Obs.	1160	1160	1160	1160	1160	1160
Controls		✓		✓		✓
R2 Marg.			0.042	0.050	0.020	0.131
R2 Cond.			0.860	0.875		

Notes:* p < 0.05, ** p < 0.01, *** p < 0.001. Symmetric APE contract combination is set as the base level. GLM and GLMM models: Coefficients are in log-odds for intercept and log-odds ratios for predictors. LPM models: Regressions are estimated with an OLS approach. Coefficients are in the marginal probabilities. Cluster-robust standard errors (for LPMs) are in parentheses.

Some of our model specifications have insignificant coefficients. Nevertheless, when both managers are compensated with RPE contracts, the changes in the log-likelihood

[17]Generalised linear mixed models are often suggested for the analysis of individual behaviour; however, incorrectly specifying the underlying data structure may potentially inflate type I error. See Litière et al. (2007).

of observing deviations remain consistently significant[18]. Thus, based on the data from a relatively small sample, we can partially confirm Hypothesis 4.

Result 5 *When both managers are incentivised by Relative Performance Evaluation (RPE) contracts, the likelihood of deviating from explicit agreements increases.*

Additional analysis

Finally, we take a look at the effects of explicit agreements. First, we calculate the mean of individual compensation and the resulting profit under each contract allocation. We then look at the difference between the observed payoffs in the markets where explicit agreement has been reached and where it has not been reached. We present the results in Table 3.4.6.

Table 3.4.6: Profits and Compensation for each Contract Allocation

	No Explicit Agreement			Explicit Agreement			Difference	
Market Type	n	Comp	Profit	n	Comp	Profit	Δ Comp	Δ Profit
APEvAPE	600	1095.21(14.92)	998.71(14.5)	320	1323.39(5.58)	1223.39(5.58)	228.18(15.92)	224.68(15.54)
APEvRPE	610	953.66(14.67)	859.48(14.07)	280	1310.98(6.04)	1210.98(6.04)	357.32(15.86)	351.5(15.31)
RPEvAPE	610	1116.52(20.63)	939.18(14.8)	280	1319.89(9.45)	1215.43(5.95)	203.36(22.69)	276.25(15.96)
RPEvRPE	580	872.87(20.11)	774.56(15.9)	280	1195.79(22.38)	1096.93(19.52)	322.92(30.09)	322.37(25.17)

Table 3.4.6 offers two interesting observations. First, contrary to the mechanism behind strategic delegation, introducing RPE-based bonuses strictly lowers the profits of the company when there is no communication, even if the rival firm uses APE-based compensation for their manager. Second, the incentives to form explicit agreements (based on the combined increase in managerial compensation) are the lowest in the markets where managers are compensated with APE contracts.

3.5 Discussion

In this experimental study, we investigate the effects of executive compensation based on relative performance evaluation (RPE) on market efficiency and, in particular, on the incidence of collusive behaviour. Although this type of executive compensation is becoming increasingly important from an antitrust perspective, as the use of RPEs in executive compensation has gained popularity in recent years (Do et al., 2022) and economic theory suggests that it can influence collusive behaviour (Matsumura and Matsushima, 2012; Guigou and de Lamirande, 2015), there is almost no empirical evidence to date of a link between RPE-based executive compensation and collusive behaviour. Only the finding from the study by Bloomfield et al. (2023) that firms that form a cartel are more likely

[18] In the linear probability models, the coefficients associated with symmetric RPE markets are significant at a 10 per cent level.

to use RPE in the remuneration of their top managers provides indirect evidence of a link between RPE-based compensation and collusive behaviour. However, the study by Bloomfield et al. is based on observational data, so that the correlation found cannot be interpreted as causal.

To investigate the causal effects of RPE-based compensation on managers' collusive behaviour, we conducted an economic experiment in which subjects make quantity decisions in a repeated duopoly and are exposed to two treatments. First, the number of managers compensated by RPE-based bonuses varies: in a market, no manager, one manager, or two managers receive this remuneration. Second, subjects are either restricted from communicating and can, therefore, only make tacit agreements, or they are allowed to communicate and can, therefore, make explicit agreements. Our study thus contributes to the already established experimental literature on tacit collusion Engel (2015), in which the effect of RPE-based compensation of managers has not yet been investigated. By including the possibility of explicit agreements, our experiment also contributes to recent work on the stability of cartels (Engel, 2007; Fonseca et al., 2018), as we empirically investigate whether stability is causally related to the number of managers whose compensation is RPE-based.

When only tacit collusion is possible, our experimental results are consistent with our theoretical predictions: the presence of managers incentivised by RPE-based bonuses leads to a statistically significant increase in observed market quantities. Therefore, this result suggests that RPE-based bonuses increase consumer surplus and overall social welfare. This observation can largely be attributed to the differences in Nash equilibria resulting from the change in best-response functions (Jansen et al., 2008). Although RPE bonuses are theoretically expected to prevent both perfect and tacit collusion by increasing the critical discount factors (Matsumura and Matsushima, 2012; Guigou and de Lamirande, 2015), our results show that RPE contracts have no statistically significant effect on the likelihood of cartels and partial collusion.

When communication between managers (subjects) is allowed, and subjects can make explicit agreements, the observed market quantities are significantly lower than without communication, regardless of the number of managers incentivised by RPE-based compensation. We observe a significantly higher probability of cartel-like behaviour in line with previous research (Hanaki and Ozkes, 2022). Since the communication in our experimental setup is perfectly observable, we can also detect whether subjects deviate from the explicit quantity agreements they made in the chats before the supergames. Our results show that the probability of deviating from the explicit agreements increases when both managers are incentivised by RPE-based bonuses. This suggests that RPE-based bonuses can destabilise cartels and act as an *internal* factor influencing cartel stability in addition to the external factors that have been shown to be relevant in previous research, such as the legal environment (Bodnar et al., 2021) or sanctioning institutions (Andres et al., 2021).

Our study is also related to experimental studies on strategic delegation that primarily focus on the decisions of firm owners to use certain compensation schemes to induce their managers to behave more aggressively (Huck et al., 2004a; Georgantzís et al., 2008; Du et al., 2013; Kim, 2022). However, in contrast to these experimental studies, the type of managerial compensation in our experimental design is not chosen by the firm owners (subjects) but is entirely exogenous. This allows us to interpret the effects of executive compensation on managerial decision-making as causal, which is not the case in the experimental studies on strategic delegation.

Our study has implications for competition policy and antitrust authorities. Competition authorities in the UK and the US already recognise the importance of RPE-based compensation schemes to filter shocks and promote higher levels of executive performance (Farmer et al., 2013). We provide convincing arguments that, from the perspective of competition authorities, selecting direct competitors as part of the peer group for RPE-based executive compensation is pro-competitive. Our results show that this form of executive compensation increases allocative efficiency. We also find that managers are more likely to deviate from explicit antitrust agreements when compensated in this way. Consequently, RPE-based compensation may tend to undermine cartels from within. The effect of RPE-based bonuses for managers would go in the same direction as external measures such as monitoring, sanctioning regimes or leniency programmes (Andres et al., 2021; Fonseca et al., 2022; Andres et al., 2023).

As with any economic experiment, questions arise with regard to external validity. Our experimental design refers to markets that are characterised by high concentrations (duopolies). Furthermore, the relative performance evaluation in our experimental design uses only the direct competitor's profit as a benchmark. In practice, however, it is quite possible that companies that are not in direct competition also serve as benchmarks (Gong et al., 2011; Bizjak et al., 2022; Feichter et al., 2022). Future experimental studies could investigate the extent to which the results change when non-competitors also serve as benchmarks. Moreover, in our experimental design, communication can only occur before the supergames. Previous experimental work suggests that this restricted form of communication is sufficient to establish collusion (Cooper and Kühn, 2016), and cooperation between firms continues even after communication is disabled (Fonseca and Normann, 2012). However, a recent study of field data by Haucap and Heldman (2023) reveals that persistent communication is important in stabilising cartels, particularly in noisy environments. This claim is further supported by experimental work (Cooper and Kühn, 2016; Bigoni et al., 2018). Hence, there is a clear imperative for conducting further research on the destabilising effects of RPEs in different environments and different modes of communication.

In interpreting our findings, it is also important to recognise that the reported results are preliminary and derived from a relatively small sample. Two problems, in particular, exacerbate this limitation. Firstly, there is the matter of alternating monopoly, which we address in Appendix 3.B. Moreover, during our initial session, we encountered several technical issues that prevented some participants from accessing the chat. Although we exclude both types of problematic markets in our analysis of explicit agreements, these problems led to further reductions in our sample size. Nevertheless, the suggestive evidence that we do find in the remaining sample produces statistically significant results. Thus, we are optimistic that these findings will remain robust after further data collection procedures.

3.6 Conclusion

Executive compensation schemes that change over time play a central role in firm-level decisions and consequently influence market efficiency and competitive dynamics. This experimental study examines the competitive effects of executive bonuses based on relative performance evaluation, which has gained popularity in recent years. For concentrated markets, where the profits of direct competitors serve as the basis for relative performance evaluation, our results show that this form of executive compensation has positive effects on allocative efficiency and makes collusive behaviour less likely. Previous research on the determinants of collusive behaviour has focused on factors external to the firm, but our results show that factors internal to the firm, such as executive compensation, also play a role. Therefore, we believe that this direction remains a fruitful field for experimental industrial economics research.

Appendix 3.A: Additional Tables

Table 3.A.1: Demographics: Overall Sample and Subsamples

Characteristic	**Overall**, N = 96	**No Communication**, N = 56	**Communication**, N = 40
Gender			
Female	46 (48%)	27 (48%)	19 (48%)
Male	33 (34%)	18 (32%)	15 (38%)
Other/Prefer not to say	17 (18%)	11 (20%)	6 (15%)
Student	94 (98%)	55 (98%)	39 (98%)
Age Group			
18-21	30 (31%)	14 (25%)	16 (40%)
22-25	33 (34%)	23 (41%)	10 (25%)
26-30	16 (17%)	9 (16%)	7 (18%)
31-35	1 (1.0%)	0 (0%)	1 (2.5%)
36-40	1 (1.0%)	0 (0%)	1 (2.5%)
40+	1 (1.0%)	1 (1.8%)	0 (0%)
Other/Prefer not to say	14 (15%)	9 (16%)	5 (13%)
University of Wuppertal	32 (33%)	24 (43%)	8 (20%)
Participant Payoff	16.8 (14.8, 20.9)	15.4 (13.1, 18.3)	20.4 (16.8, 23.6)

[1] n (%); Median (IQR)

Table 3.A.2: Regression Analysis - Observed Quantities (RPE as a factor)

Subsample:	No Communication (NC)		Communication (C)		Pooled	
Model	1	2	3	4	5	6
Intercept	68.06***	64.12***	54.94***	60.17***	68.06***	67.94***
	(1.97)	(2.88)	(2.06)	(3.23)	(1.97)	(2.65)
$APEvRPE$	6.20*	6.20*	0.09	0.09	6.20*	6.20*
	(2.47)	(2.47)	(2.58)	(2.55)	(2.47)	(2.52)
$RPEvRPE$	9.87**	9.88***	4.51	4.51	9.87**	9.88**
	(3.03)	(2.98)	(3.83)	(3.55)	(3.03)	(3.03)
C					−13.12***	−13.12***
					(2.85)	(2.79)
$C \times APEvRPE$					−6.11	−6.11
					(3.57)	(3.52)
$C \times RPEvRPE$					−5.37	−5.37
					(4.88)	(4.75)
Num.Obs.	1120	1120	800	800	1920	1920
Controls		✓		✓		✓
R2 Marg.	0.056	0.074	0.023	0.125	0.308	0.324
R2 Cond.	0.579	0.595	0.766	0.773	0.740	0.746

Notes: Regression specification $Y_{ij} = \beta_{0,1,2}FRPE_{ij} + \beta_{3,4,5}FRPE_{ij} \times C_i + Controls + e_{ij}$ where $FRPE_{ij}$ is a factor variable representing different contract combinations (where no, one, or both managers have RPE-based contract) the rest of the notation is the same as in Eq. 3.13. The symmetrical APE combination is set as the base level. Significance levels at *p < 0.05, **p < 0.01, ***p < 0.001. Cluster-robust standard errors are in parentheses.

Table 3.A.3: Regression Analysis - Observed Quantities (RPE as a dichotomous variable)

Subsample:	No Communication (NC)		Communication (C)		Pooled	
Model	1	2	3	4	5	6
Intercept	68.06***	64.13***	54.94***	60.17***	68.06***	67.94***
	(1.97)	(2.88)	(2.06)	(3.29)	(1.97)	(2.66)
$BRPE$	7.43**	7.43**	1.56	1.56	7.43**	7.43**
	(2.34)	(2.32)	(2.55)	(2.49)	(2.34)	(2.38)
C					−13.12***	−13.12***
					(2.85)	(2.79)
$C \times BRPE$					−5.87	−5.87
					(3.46)	(3.40)
Num.Obs.	1120	1120	800	800	1920	1920
Controls		✓		✓		✓
R2 Marg.	0.047	0.065	0.003	0.106	0.300	0.316
R2 Cond.	0.576	0.593	0.764	0.771	0.739	0.745

Notes: Regression specification $Y_{ij} = \beta_0 + \beta_1 BRPE_{ij} + \beta_2 C_i + \beta_3 C_i \times BRPE_{ij} + Controls + e_{ij}$ where $BRPE_{ij}$ is a dichotomous variable taking the value 1 if there is at least one RPE contract, present in the market and 0 otherwise. The rest of the notation is the same as in Eq. 3.13. Significance levels at *p < 0.05, **p < 0.01, ***p < 0.001. Cluster-robust standard errors are in parentheses.

Appendix 3.B: Alternating Monopoly

Alternating monopoly (AM) is a strategy in a repeated market setting where firms alternate between producing monopoly output and no output. Although such interaction is possible, it is unlikely to happen in real markets[19]. Generally, this behaviour is not problematic in experimental market environments. However, due to non-negative constraints on the RPE-based compensation, participants in our setting are able to achieve significantly higher profits. In this section, we first describe the implications of alternating monopoly strategy in the context of our theoretical framework, then explain the problems with our experimental setting, and conclude with a simple fix.

Theoretical implications

Consider an infinitely repeated Cournot game with linear demand and constant marginal costs $c = 0$.

$$P = 1 - q_i - q_j \tag{3.15}$$

$$\Pi_i = (1 - q_i - q_j)q_i \tag{3.16}$$

If firms i and j coordinate and split the market (SM), each produces half of the monopoly output ($\frac{1}{4}$) and gets half of the monopoly profit $\Pi_i^C = \Pi_j^C = 0.5\Pi^M = \frac{1}{8}$. As in section 3.2.2, we can calculate the critical minimum discount factor(δ^{SM}) necessary to sustain collusion. For this, consider that firm j cooperates in every period unless firm i cheats. Firm i's choice is between cooperation and choosing the best response to the half of the monopoly output $\frac{1}{4}$:

$$q_i^*(q_j = \frac{1}{4}) = \frac{3}{8} \implies \Pi_i^D = \frac{9}{64}$$

The consequence for deviating is the grim trigger response by firm j, which would play Cournot equilibrium quantity $\frac{1}{3}$, thus ensuring $\Pi_i^E = \Pi_j^E = \frac{1}{9}$ for the rest of the game. Assuming constant discounting factor (δ), firm i would choose to continue to cooperate if:

$$\Pi_i^C(\frac{1}{1-\delta}) > \Pi_i^D + \frac{\delta}{1-\delta}\Pi_i^E \tag{3.17}$$

Or if

$$\delta > \delta^{SM} = \frac{\Pi_i^D - \Pi_i^C}{\Pi_i^D - \Pi_i^E} = \frac{9}{17} \tag{3.18}$$

[19]For examples where AM is feasible, see Herings et al. (2005) and Amelio and Biancini (2010).

Similarly, we can calculate the critical minimum discount factor for the alternating monopoly strategy. In all even periods ($t = 2, 4, ...$) firm i does not produce any output and receives no profits, while firm j produces monopoly output and gets monopoly profits $\Pi^M = \frac{1}{4}$. In all uneven periods, they switch. Thus, without discounting, both AM and SM strategies yield the same average per-period benefit as forming a cartel ($\frac{\Pi^M}{2} = \frac{1}{8}$) for each firm. Suppose the firms agree to play AM and $\delta < 1$. In that case, the firm that produces no output in period $t = 1$ is already disadvantaged since future monopoly profit will be discounted in the next period. Without loss of generality, assume it is firm i. Thus, firm i's discounted profits from cooperating under AM are:

$$\Pi_i(\mathit{Total,\ Cooperate}) = 0 + \Pi_i^M(\frac{\delta}{1-\delta^2}) = \frac{\delta}{4(1-\delta^2)} \tag{3.19}$$

The discounted profits after deviating (choosing to best respond to the *monopoly output*) in period $t = 1$ are:

$$\Pi_i(\mathit{Total,\ Deviate}) = \frac{1}{16} + \frac{\delta}{9(1-\delta)} \tag{3.20}$$

The critical minimum discount factor necessary to sustain collusion can then be calculated as follows:

$$\delta^{AM} = \frac{10-\sqrt{37}}{7} \approx 0.5596 > \delta^{SM} \approx 0.5294 \tag{3.21}$$

In other words, collusion under the AM strategy is relatively harder to sustain than the SM strategy.

In our theoretical framework (Section 3.2), we assume that the managers are evaluated each period, and their (symmetric) compensation is:

$$V^{RPE} = \Pi_i + \gamma(\Pi_i - \Pi_j) \tag{3.22}$$

Following the same reasoning as above, we can calculate the benefit of agreeing to play the AM strategy. Thus, in period ($t = 1$), firm i would produce 0. The compensation of the manager would, thus, be:

$$V_{t=1}^{RPE} = 0 + \gamma(0 - \Pi^M) = -\frac{\gamma}{4} \tag{3.23}$$

The discounted profits from cooperating are then:

$$V_i^{RPE}(\mathit{Cooperating,\ Total}) = -\frac{\gamma}{4(1-\delta^2)} + \frac{(1+\gamma)\delta}{4(1-\delta^2)} = \frac{\gamma\delta+\delta-\gamma}{4(1-\delta^2)} \tag{3.24}$$

The discounted profits after deviating (choosing to best respond to the *monopoly output*) in period $t = 1$ are:

$$V_i^{RPE}(\textit{Total, Deviate}) = \frac{1}{16+16\gamma} + \frac{\delta(\gamma+1)}{(2\gamma+3)^2(1-\delta)} \tag{3.25}$$

We simplify the calculation by choosing $\gamma = 1$ as in our experiment. We can then compare critical minimum discount factors under AM and SM (See Table 3.4.6) for the RPE-based contract.

$$\delta_{RPE}^{AM} = \frac{56-\sqrt{2161}}{13} \approx 0.73 > \delta_{RPE}^{SM} \approx 0.61 \tag{3.26}$$

The above equation suggests that RPE-based compensation makes the AM strategy even less stable.

Problems with experimental setting

We have used a non-negative constraint for both contract types as described in section 3.3. Thus, for the APE-based contract, the participants' payoff is:

$$v_i^{ape} = \begin{cases} \pi_i + 100 & \pi_i > 0 \\ 0 & \text{otherwise} \end{cases} \tag{3.27}$$

In the case of the RPE bonus scheme, the reward of the manager depends on the profits of both firms:

$$v_i^{rpe} = \begin{cases} \pi_i + 100 + (\pi_i - \pi_j) & v_i^{rpe} > 0 \\ 0 & \text{otherwise} \end{cases} \tag{3.28}$$

The non-negativity constraint in v_i^{ape} does not influence either AM or SM strategies, as compensation in both is not negative. Thus, inequality 3.21 remains true. However, under the RPE contract, Equation 3.24 becomes

$$V_i^{RPE}(\textit{Cooperating, Total}) = \frac{(1+\gamma)\delta}{4(1-\delta^2)} \tag{3.29}$$

In other words, by playing the AM strategy, the manager of firm i gets $(1+\gamma)$ monopoly profits in every even period and 0 for every uneven period. For $\gamma = 1$, this implies

$$\delta_{RPE}^{AM} = \frac{168-\sqrt{27249}}{39} \approx 0.075 < \delta_{RPE}^{SM} \approx 0.61 \tag{3.30}$$

In other words, the AM strategy under RPE contracts produces the strongest explicit agreements (even more stable that APE contracts). Furthermore, the joint compensation under alternating monopoly strategy Pareto dominates the joint compensation under the market share strategy (since *both* managers receive above monopoly compensation). Therefore, by bounding the RPE contract above 0, we have unintentionally induced participants to play the AM strategy.

Solution

Alternating monopoly strategy produces the same total market outcome as the "normal" collusion (monopoly output). However, the validity of our theoretical predictions may be compromised, as under the AM strategy, the incentive to deviate is *lower* for RPE-based contracts. This issue is irrelevant to the No Communication treatment, as it requires strong coordination between participants and an "aha" moment in the understanding of our setting. However, we do identify cases of the AM strategy in Communication Treatment, presented in Table 3.B.1.

Table 3.B.1: Communication Treatment: Observed Cases of Alternating Monopoly

Market Type	Total Observations	Alternating Monopoly	Proportion (AM)
APE v APE	200	20	0.100
APE v RPE	400	70	0.175
RPE v RPE	200	50	0.250

In the current version of our paper, the solution for this issue is quite direct. Theoretical predictions in the main body of our paper hold as long as communication between participants does not result in the AM strategy. Thus, after excluding all markets that adopt the AM strategy, we can evaluate the strength of explicit agreements (as in Hyp. 4). Notably, the omission of markets using the alternating monopoly strategy does not alter the significance or direction of our other findings (e.g., results 1 - 4).

There are two possible ways to handle future data collection. The first approach is to keep the environmental setting constant and use the same procedures for AM data as in the current version. However, assuming the same rate of AM strategy adoption, this approach would result in 20 per cent data loss (due to the exclusion of AM markets). Alternatively, it is possible to introduce a non-negativity constraint on *total compensation for all payoff-relevant periods* instead of per-period compensation. In this way, the alternating monopoly strategy under RPE contracts would still contain negative elements as in Equation 3.24, and therefore, would be less stable and not Pareto optimal. Current data suggests that relaxing per-period non-negativity constraint would not significantly affect the data, as less than 0.1 per cent of markets have quantities above 90.

Appendix 3.C: Experimental Instructions

Experimental instructions are presented in the sequence they are shown to participants. Where pages vary between treatments, both versions are displayed. The content of each page can be summarised as follows (both German and English translations):

1. Introduction to the experiment.
2. Information about the market environment and several illustrative examples of the calculations.
3. Introduction to the calculator and control questions. By moving the sliders, participants change quantities and receive immediate feedback on their profits, other firm's profits, and the resulting compensation under both contracts. Participants can proceed only after they have answered the control questions correctly.
4. Information about market duration, payoffs, and exchange rates. Additionally, participants had the opportunity to engage in a practice round, choosing quantities for both firms to see potential payoffs.
5. Announcement page for the start of payoff-relevant rounds. In the case of the Communication treatment, participants were informed about the online chat feature.
6. Notification about successful matching. Details about the participant's contract for the current supergame and their matched partner's contracts are provided. In the Communication treatment, the page also features a chat window and the profit calculator. This page is limited to 3 minutes and 30 seconds.
7. An example of a round that is relevant for payoffs. This window also showcases the history of prior interactions with the matched participant.
8. Announcement of the rematching process after the conclusion of the previous supergame.

Einführung in das Experiment

Allgemeine Anweisungen

Hallo und herzlich willkommen zu unserem Experiment. Bitte lesen Sie diese Anweisungen sorgfältig durch.

Sie nehmen an einem Experiment teil, in dem es darum geht, Entscheidungen zu treffen. Die Höhe Ihres Verdienstes hängt von einer Kombination Ihrer eigenen Entscheidungen, den Entscheidungen anderer Personen und dem Zufall ab. Bitte schalten Sie Ihr Mobiltelefon sowie andere elektronische Geräte nun aus. Während des Experiments ist es Ihnen untersagt mit anderen Teilnehmer*innen zu sprechen.
Das Experiment dauert voraussichtlich 75 bis 90 Minuten. Das Experiment wird anonym durchgeführt. Sie werden also nicht wissen, mit wem Sie interagieren.

Wir beginnen mit einer kurzen Einführung. Diese gibt Ihnen einen Überblick über die wichtigsten Elemente des Experiments. Wenn Sie Fragen haben, heben Sie bitte die Hand und Ihre Frage wird laut und für alle hörbar beantwortet.

Alle Informationen, die wir von Ihnen erhalten, werden vertraulich behandelt. Das Experiment ist anonym. Ihre Antworten werden ausschließlich zu wissenschaftlichen Zwecken verwendet. Das Projekt wurde ausführlich von der Ethikkommission der Bergischen Universität Wuppertal geprüft, die ein positives Votum zur Unbedenklichkeit der geplanten Studie abgegeben hat.

Wenn Sie auf "Weiter" klicken, erklären Sie sich damit einverstanden, an diesem Experiment teilzunehmen.

Weiter

Informationen

Allgemeine Informationen

Die Anweisungen sind in drei Teile unterteilt:

- Marktumfeld (diese Seite): Sie werden Entscheidungen in einem Marktumfeld treffen und hier erhalten Sie Informationen darüber, wie der Markt funktioniert, einige Beispiele für Ihre Entscheidungen und Details zu möglichen "Verträgen".
- Rechner: Hier erhalten Sie eine Beschreibung des Rechners, der Ihnen bei der Entscheidungsfindung hilft.
- Hauptteil des Experiments: Hier erhalten Sie Informationen über Ihre Bezahlung, wie lange die Märkte betrieben werden und Sie haben die Möglichkeit in einer Übungsrunde das Marktumfeld besser zu verstehen.

Marktumfeld

Während des Entscheidungsteils des Experiments werden Sie gebeten, die Rolle der Leitung eines Unternehmens zu übernehmen und Entscheidungen im Namen des Unternehmens im Marktumfeld zu treffen. Ihr Unternehmen wird sich auf einem Markt mit einem anderen Unternehmen befinden, das von einer anderen teilnehmenden Person geleitet wird, die dieselben Anweisungen liest.
Die Entscheidungen, die Sie und die andere teilnehmende Person treffen, bilden die Grundlage Ihrer Vergütung.

Im Experiment werden Experimental Points als Währung verwendet. Der Wechselkurs beträgt 1000 Experimental points (EP) = 1 EUR.
Auf einem Markt befinden sich Ihr Unternehmen (Firma X) und ein anderes Unternehmen (Firma Y) die beide das Gut Z produzieren. Jedes der beiden Unternehmen produziert eine bestimmte Menge des Guts.
Ihre Entscheidung besteht darin, eine Produktionsmenge für Ihr Unternehmen (Firma X) zu wählen. Die andere teilnehmende Person wählt eine Menge für das Unternehmen Y.
Der Preis für Gut Z ergibt sich wie folgt:

Preis = 100 - (Menge von Firma X + Menge von Firma Y)
HINWEIS: Wenn die Gesamtmenge über 100 liegt, beträgt der Preis 0.

Der Gewinn jedes Unternehmens wird wie folgt berechnet:
Gewinn = vom Unternehmen produzierte Menge * Preis

Beispiel 1

Angenommen, Sie wählen eine Menge von 30 und die andere teilnehmende Person wählt eine Menge von 40.
Der Preis für das Gut Z beträgt dann:
Preis = 100 - (30 + 40) = 30
Der Gewinn jedes Unternehmens wird wie folgt berechnet:
Gewinn Ihres Unternehmens = 30(Preis) * 30 (Ihre Menge) = 900
Gewinn des anderen Unternehmens = 30(Preis) * 40 (Menge der anderen teilnehmenden Person) = 1200

Beispiel 2

Angenommen, Sie wählen eine Menge von 50 und die andere teilnehmende Person wählt eine Menge von 70.
Der Preis für das Gut Z beträgt dann:
Preis = 100 - (50 + 70) = -20 < 0, daher beträgt der Preis 0.
Der Gewinn jedes Unternehmens wird wie folgt berechnet:
Gewinn Ihres Unternehmens = 0(Preis) * 50 (Ihre Menge) = 0
Gewinn des anderen Unternehmens = 0(Preis) * 70 (Menge der anderen teilnehmenden Person) = 0

Vergütung

Im Verlauf des Experiments werden Sie basierend auf zwei möglichen Verträgen vergütet.
Vertrag A: Ihre Vergütung = (Gewinn Ihres Unternehmens) + 100
HINWEIS: 100 wird nur hinzugefügt, wenn Ihre Gewinne positiv sind.
Im obigen Beispiel 1 beträgt Ihre Vergütung unter Vertrag A dann:
Ihre Vergütung = 100 + 900 = 1000 EP
Im obigen Beispiel 2 beträgt Ihre Vergütung unter Vertrag A dann:
Ihre Vergütung = 0 + 0 = 0 EP

Vertrag B: Ihre Vergütung = (Gewinn Ihres Unternehmens) + (Gewinn Ihres Unternehmens - Gewinn des anderen Unternehmens) + 100
HINWEIS: 100 wird nur hinzugefügt, wenn Ihre Gewinne positiv sind.
Im obigen Beispiel 1 beträgt Ihre Vergütung unter Vertrag B dann:
Ihre Vergütung = 100 + 900 + 900 - 1200 = 700 EP
Im obigen Beispiel 2 beträgt Ihre Vergütung unter Vertrag A dann:
Ihre Vergütung = 0 + 0 + 0 - 0 = 0 EP

Weiter

Informationen

Rechner

Um Ihnen die Entscheidung zu erleichtern, stellen wir Ihnen einen Rechner zur Verfügung. Mithilfe dieses Rechners werden Ihnen die Gewinne der Unternehmen und Ihre Vergütung (auf der Grundlage des Ihnen zugeteilten Vertrags) dargestellt.

Vergütung

In dieser Einführung wird die Vergütung anhand von zwei verschiedenen Verträgen dargestellt.

Vertrag A: Ihre Vergütung = 100 + (Gewinn Ihres Unternehmens)

Vertrag B: Ihre Vergütung = 100 + (Gewinn Ihres Unternehmens) + (Gewinn Ihres Unternehmens - Gewinn des anderen Unternehmens)

Während der Entscheidungsphasen wird nur der Vertrag angezeigt, dem Sie zugewiesen sind.

Rechner

Wählt die andere teilnehmende Person: 4

0 10 20 30 40 50 60 70

Und Sie wählen: 17

0 10 20 30 40 50 60 70

Unternehmensgewinne und Ihre Vergütung

Vertrag	Gewinn der anderen Firma	Gewinn meiner Firma	Mein Bonus	Meine Vergütung
Vertrag A:	**316**	**1343**	**100**	**1443**
Vertrag B:	**316**	**1343**	**1127**	**2470**

Wie der Rechner funktioniert:

Wenn Sie die Position des Schiebereglers für ein beliebiges Unternehmen ändern, können Sie die neuen Gewinne sehen, die sich aus dieser spezifischen Kombination von Mengen ergeben. Sie können auch Ihre Vergütung basierend auf den Gewinnen sehen.

Vertrag A zahlt Ihren Gewinn + den Bonus der festen Zahlung von 100, wenn Ihr Gewinn positiv ist.

Vertrag B zahlt Ihren Gewinn + den Bonus von 100 + die *Differenz zwischen Ihren Gewinnen und den Gewinnen der anderen teilnehmenden Person*.

Wenn Sie also mehr produzieren als die andere Person, die Ihnen zugewiesen ist, erhalten Sie bei Vertrag B für eine bestimmte Mengenkombination mehr als Vertrag A.

Wenn Sie jedoch unter Vertrag B *weniger* als die andere teilnehmende Person produzieren, kann Ihr Bonus negativ sein. (Zum Beispiel, wenn Sie 10 für Ihr Unternehmen und 40 für das andere Unternehmen auswählen).
Ihre Gesamtvergütung wird jedoch nicht unter 0 fallen.

Hier sind einige Verständnisfragen. Alle Antworten können mit einem Rechner ermittelt werden.

Sie können nur fortfahren, wenn Sie diese Fragen korrekt beantworten.

Wenn die andere Person eine Menge von 25 wählt und Sie ebenfalls eine Menge von 25 wählen, wie hoch ist dann Ihre Vergütung gemäß Vertrag A?

1250

Angenommen, die andere Person wählt eine Menge von 24. Welche Menge führt unter Vertrag B zu der höchsten Vergütung?

44

Angenommen, die andere Person eine Menge von 33 wählt und Sie ebenfalls eine Menge von 33 wählen. Wie hoch wird Ihre Vergütung gemäß Vertrag A sein?

1222

Weiter

Informationen: Hauptteil des Experiments

Allgemein

Im Hauptteil des Experiments agieren Sie als Unternehmensleitung in 4 Märkten. Jeder Markt dauert mehrere Perioden.
In jedem Markt werden Sie mit einer anderen teilnehmenden Person gematcht. Ihnen werden Informationen über Ihren Vertrag, den Vertrag der teilnehmenden Person, mit der Sie gematcht sind, ein Rechner ähnlich dem auf der vorherigen Seite und Details über die Ergebnisse in den vorherigen Perioden gegeben.

Ihre Vergütung

Nachdem Sie in vier Märkten im Hauptteil des Experiments Entscheidungen getroffen haben, werden wir zufällig einen Markt (von 4) auswählen und Ihnen die Gesamtvergütung aus diesem Markt auszahlen. Zusätzlich erhalten Sie auch Ihre Teilnahmegebühr von 5,00 € EUR.
Das Experiment verwendet einen Wechselkurs von 1000 Experimental Points (EP) = 1 Euro.

Dauer der Märkte

- In zehn oder mehr Perioden werden Sie Entscheidungen treffen.
- Ihre Vergütung hängt davon ab, ob der Markt besteht oder nicht.
- Falls der Markt vor **10** Perioden endet, dann treffen Sie zwar in zehn Perioden Entscheidungen, jedoch werden für Ihre Vergütung nicht 10 Perioden berücksichtigt, sondern nur diejenigen Perioden bis Ende des Marktes.
- Falls der Markt nach **10** Perioden endet, dann treffen Sie Entscheidungen solange der Markt besteht und es werden für Ihre Vergütung alle Perioden bis Ende des Marktes berücksichtigt.
- In jeder Periode beträgt die Wahrscheinlichkeit, dass der Markt nach dieser Periode weiterhin besteht, **90%**.
- Diese Wahrscheinlichkeit wird wie folgt ermittelt: für jede Periode generiert der Computer eine Zufallszahl zwischen 1 und 10. Wenn eine Zahl für eine Periode 10 ist, dann endet der Markt.

1. Vergütungsbeispiel

Angenommen, die Zufallsziehung (die Ihnen erst am Ende des Experiments gezeigt wird) lautet [1,5,1,6,8,2,9,1,10]. In diesem Beispiel spielen Sie 10 Runden, aber nur die ersten 9 sind relevant für die Vergütung. Das liegt daran, dass das zufällige Ergebnis 10 in Runde 9 auftrat.
Sie erhalten also die Summe der Vergütungen für die ersten 9 Runden.

2. Vergütungsbeispiel

Angenommen, die Zufallsziehung (die Ihnen erst am Ende des Experiments gezeigt wird) lautet [1,5,1,6,8,2,9,1,3,7,5,10]. In diesem Beispiel spielen Sie 12 Runden, und alle Runden sind relevant für die Vergütung. Das liegt daran, dass das zufällige Ergebnis 10 in Runde 12 auftrat.
Sie erhalten also die Summe der Vergütungen für alle 12 Runden.

Marktbeispiel

Unten sehen Sie ein Beispiel für den Markt, bei dem Sie die Mengen sowohl für sich selbst als auch für eine andere Firma wählen können.
Für diesen Beispielmarkt ist Ihr Vertrag **VERTRAG A:**
Daher beträgt Ihre Gesamtvergütung IHREN GEWINN + 100.

Rechner

Wählt die andere teilnehmende Person: 9

0 10 20 30 40 50 60 70

Und Sie wählen: 45

0 10 20 30 40 50 60 70

Unternehmensgewinne und Ihre Vergütung

Gewinn der anderen Firma	Gewinn meiner Firma	Mein Bonus	Meine Vergütung
414	**2070**	**100**	**2170**

Der Gewinn Ihres Unternehmens beträgt 2070. Ihr Bonus beträgt 100. Ihre Gesamtvergütung beträgt 2170.

Ihre Mengenauswahl: 13
Mengenauswahl für das andere Unternehmen: 22
Wählen

Frühere Ergebnisse:

Meine Produktion	Produktion der anderen Firma	Gewinn meiner Firma	Gewinn der anderen Firma	Meine Vergütung
13	22	845.00	1430.00	945.00
13	22	845.00	1430.00	945.00
13	22	845.00	1430.00	945.00
13	22	845.00	1430.00	945.00

Bitte führen Sie mindestens 10 Übungsrunden aus, um die endgültigen Beispielauszahlungen zu sehen.

Weiter

Das Haupexperiment beginnt nun.

Alle Entscheidungen, die Sie in den nächsten Runden treffen, können für Ihre endgültige Gesamtvergütung relevant sein.
Wenn Sie Probleme haben, heben Sie bitte die Hand. Ein Assistent wird Ihnen in Kürze helfen.

HINWEIS: VOR JEDEM MARKT WIRD IHNEN ERLAUBT, MIT DER IHNEN ZUGEWIESENEN TEILNEHMENDEN PERSON, PER ONLINE-CHAT ZU KOMMUNIZIEREN.
Es ist Ihnen nicht gestattet, Ihre Identität preiszugeben.

Weiter

Das Haupexperiment beginnt nun.

Alle Entscheidungen, die Sie in den nächsten Runden treffen, können für Ihre endgültige Gesamtvergütung relevant sein.
Wenn Sie Probleme haben, heben Sie bitte die Hand. Ein Assistent wird Ihnen in Kürze helfen.

Weiter

Das ist ein neuer Markt (1).
Sie sind mit einer anderen teilnehmenden Person zusammengeführt worden!

Verbleibende Zeit für diese Seite: **3:15**

Anweisungen

In diesem Markt ist Ihr Vertrag **VERTRAG A**. Die teilnehmende Person, die Ihnen zugewiesen wurde, hat einen Vertrag **VERTRAG A**.

Bitte treffen Sie eine Auswahl für die Menge des Gutes, das Sie produzieren möchten.

Der Marktpreis beträgt PREIS = 100 - (Ihre Menge) - (Menge, die von einer anderen teilnehmenden Person gewählt wurde).

Die Gewinne betragen (PREIS * MENGE).

Ihre Gesamtvergütung für diese Runde beträgt GESAMTVERGÜTUNG = (Ihr Gewinn) + 100.

Kommunikation

Sie dürfen nun mit der teilnehmenden Person kommunizieren, die Ihnen zugewiesen wurde. Sie haben die Möglichkeit, maximal 3 Minuten lang eine Strategie in diesem Markt mit der Ihnen zugewiesenen teilnehmenden Person zu besprechen. Danach wird das Chat-Fenster geschlossen und eine weitere Kommunikation mit der Ihnen zugewiesenen teilnehmenden Person ist nicht mehr möglich.
Das Chat-Fenster befindet sich rechts neben dem Rechner.
Diese Kommunikationsoption wird nicht mit anderen teilnehmenden Personen geteilt.
Sie dürfen Ihre Identität nicht preisgeben oder Treffen mit anderen teilnehmenden Personen arrangieren.

Rechner

Wählt die andere teilnehmende Person: 23

0 10 20 30 40 50 60 70

Und Sie wählen: 11

0 10 20 30 40 50 60 70

Unternehmensgewinne und Ihre Vergütung

Gewinn der anderen Firma	Gewinn meiner Firma	Mein Bonus	Meine Vergütung
1518	726	100	826

Der Gewinn Ihres Unternehmens beträgt 726. Ihr Bonus beträgt 100. Ihre Gesamtvergütung beträgt 826.

Chat-Fenster

(Ich): Hello!

Send

Weiter

Das ist ein neuer Markt (1).
Sie sind mit einer anderen teilnehmenden Person zusammengeführt worden!

Anweisungen

In diesem Markt ist Ihr Vertrag **VERTRAG A**. Die teilnehmende Person, die Ihnen zugewiesen wurde, hat einen Vertrag **VERTRAG A**.

Bitte treffen Sie eine Auswahl für die Menge des Gutes, das Sie produzieren möchten.

Der Marktpreis beträgt PREIS = 100 - (Ihre Menge) - (Menge, die von einer anderen teilnehmenden Person gewählt wurde).

Die Gewinne betragen (PREIS * MENGE).

Ihre Gesamtvergütung für diese Runde beträgt GESAMTVERGÜTUNG = (Ihr Gewinn) + 100.

Weiter

Markt: 1, Periode: 2

Anweisungen

In dieser Runde ist Ihr Vertrag **VERTRAG A**. Die Person, die Ihnen zugewiesen wurde, hat einen Vertrag **VERTRAG A**.

Bitte treffen Sie eine Auswahl für die Menge des Gutes, das Sie produzieren möchten.

Der Marktpreis beträgt PREIS = 100 - (Ihre Menge) - (Menge, die von der anderen Person gewählt wurde).

Die Gewinne betragen (PREIS * MENGE).

Ihre Gesamtvergütung für diese Runde beträgt GESAMTVERGÜTUNG = (Ihr Gewinn) + 100.

Rechner

Wählt die andere teilnehmende Person: 4

0 10 20 30 40 50 60 70

Und Sie wählen: 32

0 10 20 30 40 50 60 70

Unternehmensgewinne und Ihre Vergütung

Gewinn der anderen Firma	Gewinn meiner Firma	Mein Bonus	Meine Vergütung
256	2048	100	2148

Der Gewinn Ihres Unternehmens beträgt 2048. Ihr Bonus beträgt 100. Ihre Gesamtvergütung beträgt 2148.

Frühere Ergebnisse (mit diesem Teilnehmer/in):

Meine Produktion	Produktion der anderen Firma	Gewinn meiner Firma	Gewinn der anderen Firma	Meine Vergütung
55	0	2475	0	2575

Wie viele Einheiten werden Sie produzieren (von 0 bis 70)?

Weiter

Das ist ein neuer Markt (2).
Sie sind mit einer anderen teilnehmenden Person zusammengeführt worden!

Anweisungen

In diesem Markt ist Ihr Vertrag **VERTRAG A**. Die teilnehmende Person, die Ihnen zugewiesen wurde, hat einen Vertrag **VERTRAG B**.

Bitte treffen Sie eine Auswahl für die Menge des Gutes, das Sie produzieren möchten.

Der Marktpreis beträgt PREIS = 100 - (Ihre Menge) - (Menge, die von einer anderen teilnehmenden Person gewählt wurde).

Die Gewinne betragen (PREIS * MENGE).

Ihre Gesamtvergütung für diese Runde beträgt GESAMTVERGÜTUNG = (Ihr Gewinn) + 100.

Weiter

Introduction to the Experiment

General instructions

Hello and welcome to our experiment. Please read this instruction set very carefully.

You are about to take part in an experiment that involves decision-making. The amount you earn will depend on a combination of your own decisions, the decisions made by others, and chance. Please ensure that your mobile phones and other similar devices are turned off. Additionally, please refrain from speaking or attempting to communicate with other participants during the experiment.
The experiment is expected to last for 1 hour 15 minutes - 1 hour 30 minutes. The experiment will be conducted anonymously, meaning that you will not know with whom you are interacting.

We will begin with a short instructional period. During this time, you will receive an overview of the main components of the experiment. If you have any questions, please raise your hand, and your question will be answered aloud for everyone to hear.

We guarantee that all information we receive from you will be treated confidentially. The game is anonymous. Your answers will only be used for scientific purposes.
The project had been discussed in detail by the ethics committee of the University of Wuppertal, which voted positively for the innocuousness of the projected study.

By clicking "Next" button, you consent to take part in this experiment.

Next

Information about the market environment

General information

The instructions are split into three parts:

- Market environment (this page): where you will get information about how the market works and some examples of your choices and the details about possible "contracts".
- Calculator: where you will get a description of the calculator - a tool that would help you to make decisions
- Main part of the experiment: where you get information about how you will be paid, how long the markets will operate and allow you to play a practice game against yourself.

Market environment

Throughout the decision part of the experiment you will be asked to assume the role of the manager of a hypothetical firm and make decisions on behalf of the firm in the market environment. Your firm will be in a market with one other firm that would be managed by another participant who is reading the same instructions.
The decisions you and the participant you are matched with will be the basis of your compensation.

The experiment would be using Experimental Points as a currency. The exchange rate is 1000 Experimental Points (EP) = 1EUR.
In a market, your firm (firm X) and another firm (firm Y) are in a market for the good Z. Each of the two firms produces a certain quantity of good.
Your decision would be to choose a quantity for your firm (firm X) . Participant you are matched with will choose a quantity for the firm Z.
The price of good Z is:

Price = 100 - (quantity produced by firm X + quantity produced by firm Y)
NOTE: if the total quantity is above 100, the price will be equal to 0.

The profit of each firm is given by:
Profit = Quantity produced by the firm * Price

Example 1

Suppose you choose a quantity of 30 and the participant you are matched with chooses a quantity of 40.
The price of good X will then be:
Price = 100 - (30 + 40) = 30
The profit of each firm is given by:
Profit of your firm = 30(Price) * 30 (your quantity) = 900
Profit of the other firm = 30(Price) * 40 (other participant's quantity) = 1200

Example 2

Suppose you choose a quantity of 50 and the participant you are matched with chooses a quantity of 70.
The price of good X will then be:
Price = 100 - (50 + 70) = -20 < 0, so the price will be 0.
The profit of each firm is given by:
Profit of your firm = 0(Price) * 50 (your quantity) = 0
Profit of the other firm = 0(Price) * 70 other participant's quantity) = 0

Compensation

Throughout the experiment you will be compensated based on two possible contracts. The same will apply to the participant you are matched with.
Contract A: Your compensation = (Profit of your firm) + 100
NOTE: 100 will only be added if your profits are positive.
In the above example 1, your compensation under Contract A will then be:
Your compensation = 100 + 900 = 1000
In the above example 2, your compensation under Contract A will then be:
Your compensation = 0 + 0 = 0

Contract B: Your compensation = (Profit of your firm) + (Profit of your firm - Profit of the other firm) + 100
NOTE: 100 will only be added if your profits are positive.
In the above example 1, your compensation under Contract B will then be:
Your compensation = 100 + 900 + 900 - 1200 = 700
In the above example 2, your compensation under Contract A will then be:
Your compensation = 0 + 0 + 0 - 0 = 0

Next

Information about the profit calculator

Calculator

To help you with your decisions, we introduce the calculator which would output firms profits and your compensation (based on your assigned contract).

Compensation

In this introduction the compensation is shown with two possible contracts.

Contract A: Your compensation = 100 + (Profit of your firm)

Contract B: Your compensation = 100 + (Profit of your firm) + (Profit of your firm - Profit of the other firm)

During the decision stages only a contract you are assigned to will be shown.

Firms' Profit Calculator

If the other participant chooses: 17

0 10 20 30 40 50 60 70

And you choose: 28

0 10 20 30 40 50 60 70

Firms' profits and your compensation

Contract	Other firm's profits	My firm's profits	My bonus	My compensation
CONTRACT A:	935	1540	100	1640
CONTRACT B:	935	1540	705	2245

How the calculator works:

Suppose you change the position of the slider for any firm. In that case, you can see the new profits resulting from that specific combination of quantities. In addition, you can see your compensation based on the profits. **Contract A pays your profit + the bonus of the fixed payment of 100 if your profit is positive.** **Contract B pays your profit + the bonus of 100 + the *difference between your profits and the profits of the other firm***

Thus, contract B pays more than contract A for a certain combination of quantities if you are producing more than the participant you are matched with.

However, if you are producing *less* than the other firm under contract B, your bonus may be negative. (For example, if you select 10 for your firm and 40 for the firm).
Your total compensation will not go below 0.

Here are some comprehension questions. All the answers can be obtained with a calculator.

You can only proceed if you answer them correctly.

Suppose the participant you are matched with produces 25 units and you produce 25 units. What will be your compensation under the contract A?

1350

Suppose the participant you are matched with produces 24 units. What quantity will result in the highest compensation under the contract B?

44

Suppose the participant you are matched with produces 33 units and you produce 33 units. What will be your compensation under the contract A?

1222

Next

Information about setting, matching and compensation

Main part of the experiment

In the main part of the experiment, you will be playing as a manager in 4 markets. Each market will last for several periods.
In each market you will be matched with a different participant. You will be given information about your contract, contract of the participant you are matched with, a calculator similar to the one on the previous page and details about the outcomes in the previous periods.

Your compensation

After you have played four markets in the main part of the experiment, we will randomly select one market (out of 4) and pay you the total compensation you have earned in that market. In addition, you will also receive your participant fee (€6.00 EUR).
The experiment is using exchange rate of 1000 Experimental Points = 1 Euro.

Duration of the markets

- You will make decisions in ten or more periods.
- Your compensation depends on whether the market exists or not.
- If the market ends before **10** periods, you will make decisions for ten periods, but only the periods until the market's end will be considered for your compensation.
- If the market ends after **10** periods, you will make decisions as long as the market exists, and all periods until the market's end will be considered for your compensation.
- In each period, the probability that the market continues to exist after that period is **90%**.
- This probability is determined as follows: for each period, the computer generates a random number between 1 and 10. If a number for a period is 10, then the market ends.

Example 1 of the compensation

Suppose the random draw (which will not be shown to you until the end of the experiment) is [1,5,1,6,8,2,9,1,10]. In this example, you will play 10 rounds, but only the first 9 will be relevant for compensation. This happens because the random outcome 10 came at round 9.
Thus, you will receive the sum of compensations for the first 9 rounds.

Example 2 of the compensation

Suppose the random draw (which will not be shown to you until the end of the experiment) is [1,5,1,6,8,2,9,1,3,7,5,10]. In this example, you will play 12 rounds, and all rounds will be relevant for compensation. This happens because the random outcome 10 came at round 12.
Thus, you will receive the sum of compensations for all 12 rounds.

Example of the market

Below you can see an example of the market where you can choose quantities both for yourself and a hypothetical other firm.
For this example market your contract is CONTRACT A.
Thus, your total compensation is YOUR PROFIT + 100.

Firms' Profit Calculator

If the other participant chooses: 44

0 10 20 30 40 50 60 70

And you choose: 23

0 10 20 30 40 50 60 70

Firms' profits and your compensation

Other firm's profits	My firm's profits	My bonus	My compensation
1452	759	100	859

Your firm`s profits are 759. Your bonus is 100. Your total compensation is 859.

Your quantity choice: 22
Quantity choice for the other firm: 11
Choose

Past History

My output	Other firm's output	My firm's profit	Other firm's profit	My compensation
22	11	1474.00	737.00	1574.00
22	11	1474.00	737.00	1574.00
22	11	1474.00	737.00	1574.00

Please play at least 10 example games to see the final example payoffs.

Next

The main part of the experiment is about to begin.

All decisions in the next rounds can be relevant to your final payment.
If you are experiencing any problems, please raise your hand and an assistant will be with you shortly.

Next

The main part of the experiment is about to begin.

All decisions in the next rounds can be relevant to your final payment.
If you are experiencing any problems, please raise your hand and an assistant will be with you shortly.

NOTE: BEFORE EACH MARKET YOU WILL BE ALLOWED TO COMMUNICATE WITH THE PARTICIPANT YOU ARE MATCHED WITH VIA ONLINE CHAT.
You are not allowed to disclose your identity.

Next

This is a new Market (1).
You have been matched with another participant!

Instructions

In this market your contract is **CONTRACT A**. The participant you are matched with has a contract **CONTRACT B** . Please make a choice for the amount of good you are to produce.

The market price is PRICE = 100 - (your quantity) - (quantity chosen by another participant)

The profits are (PRICE*QUANTITY)

Your total compensation for this round is TOTAL COMP = (Your profit) + 100

Next

This is a new Market (1).
You have been matched with another participant!

Time left to complete this page: **3:16**

Instructions

In this market your contract is **CONTRACT A**. The participant you are matched with has a contract **CONTRACT A** . Please make a choice for the amount of good you are to produce.

The market price is PRICE = 100 - (your quantity) - (quantity chosen by another participant)

The profits are (PRICE*QUANTITY)

Your total compensation for this round is TOTAL COMP = (Your profit) + 100

Communication

You are now allowed to communicate with the participant you are matched with. The chat has a maximum duration of 3 minutes to discuss your strategies in this market.
The chat window is to the right of the calculator.
This communication option will not be shared with other participants.
You are not allowed to disclose your identity or arrange meetings with other participants.

Firms' Profit Calculator

If the other participant chooses: 29

0 10 20 30 40 50 60 70

And you choose: 37

0 10 20 30 40 50 60 70

Firms' profits and your compensation

Other firm's profits	My firm's profits	My bonus	My compensation
986	1258	100	1358

Your firm`s profits are 1258. Your bonus is 100. Your total compensation is 1358.

Chat window

(Ich): Hello!

Send

Next

Market: 1, Period: 1

Instructions

In this round your contract is **CONTRACT A**. The participant you are matched with has a contract **CONTRACT B** . Please make a choice for the amount of good you are to produce.

The market price is PRICE = 100 - (your quantity) - (quantity chosen by another participant)

The profits are (PRICE*QUANTITY)

Your total compensation for this round is TOTAL COMP = (Your profit) + 100

Firms' Profit Calculator

If the other participant chooses: 11

0 10 20 30 40 50 60 70

And you choose: 20

0 10 20 30 40 50 60 70

Firms' profits and your compensation

Other firm's profits	My firm's profits	My bonus	My compensation
759	1380	100	1480

Your firm`s profits are 1380. Your bonus is 100. Your total compensation is 1480.

Past History (with this participant)

No data available

How many units will you produce (from 0 to 70)?

13

Next

This is a new Market (2).
You have been matched with another participant!

Instructions

In this market your contract is **CONTRACT A**. The participant you are matched with has a contract **CONTRACT A** . Please make a choice for the amount of good you are to produce.

The market price is PRICE = 100 - (your quantity) - (quantity chosen by another participant)

The profits are (PRICE*QUANTITY)

Your total compensation for this round is TOTAL COMP = (Your profit) + 100

Next

Chapter 4

Relative Performance Evaluation in Executive Compensation May Encourage Collusion: Why Details Matter

Abstract

This chapter explores how bonuses tied to Relative Performance Evaluation (RPE) in executive compensation can unintentionally promote collusion and improve cartel stability. The chapter consists of two parts. The first part presents a theoretical model which assumes the RPE awards to be linked to the performance of companies outside the focal firm's industry, i.e., excluding direct competitors. The chapter demonstrates that, in the case of repeated interactions, managers under RPE contracts gain more from collusive behaviour than under the standard compensation scheme. Furthermore, under certain conditions, collusion under RPE becomes easier to sustain. The RPE awards observed in practice commonly contain intervals where such conditions are satisfied. Since observational studies reach their limits in testing the theory, the second part of the chapter proposes a design of an economic experiment to test these theoretical predictions. Given the current perception of RPEs as beneficial or neutral to competition, the concerns expressed in the theoretical part and the expected results from the proposed experiment can be of immediate concern to antitrust authorities.

4.1 Introduction

Relative Performance Evaluation (RPE) has emerged as a prevalent component in executive compensation, particularly among CEOs of major corporations[1]. The practice of RPE typically involves benchmarking the firm's performance against a predetermined set of companies, providing a comparative measure of managerial effectiveness. Endorsed by government authorities for potentially enhancing shareholder value (Farmer et al., 2013), RPEs are predominantly viewed as either competition-enhancing or, at the very least, neutral in their effects on collusive tendencies (Walker, 2019). This chapter presents a contrasting perspective: under specific conditions, RPEs may yield anti-competitive outcomes.

The theoretical motivations behind RPEs are primarily based on the "informativeness principle" (Holmstrom, 1979): by evaluating CEO performance relative to the other companies, the owners can better judge managerial ability, elicit costly effort, lower contracting costs, and avoid pay-for-luck (Bizjak et al., 2022)[2]. While the primary reasons for using RPEs are internally focused, including other firms' performances in the compensation function of the manager can inadvertently have strategic implications. For example, Salas Fumas (1992) shows that by including direct competitors in the reference peer group, profit-maximising owners commit to a more aggressive response function for their management (i.e. encouraging aggressive product-market strategies). Based on this interpretation, RPEs are beneficial for social welfare as they induce competitive tendencies; yet, for the same reason, they are detrimental to the companies' profits[3].

Owners' concerns about over-aggressive market strategies can be alleviated by selecting a set of peers that do not include direct competitors or by using a broad market index (e.g., the S&P500) (De Angelis and Grinstein, 2019). Recent reports on current practices of peer group selection show that both approaches are commonly used and even suggested by compensation consultants (Ma et al., 2021). At first glance, excluding competitors or using a broad index as a benchmark implies no changes in the managers' product market strategies, as the RPE award does not provide any incentive to engage in over-aggressive behaviour. The owners can enjoy the benefits of RPE awards without harming their companies' profits (Bloomfield et al., 2023).

This chapter argues that such RPEs may be anti-competitive as they impose (perhaps unintentionally) a dual competitive dynamic: firms compete within their industry while their managers compete against other companies in their respective RPE benchmark groups. From the perspective of own payoff maximising managers, colluding on the product market level may become more attractive as it improves relative standing and

[1]Bizjak et al. (2022) report that most large US companies are using some form of RPEs.

[2]For a review of theoretical literature, see Edmans et al. (2017).

[3]RPEs with direct competitors are a special case of negatively-interdependent preferences, see strategic delegation literature (Vickers, 1985; Jansen et al., 2008; Koçkesen et al., 2000).

increases their compensation through RPE.

The theoretical part of this chapter explores a generalised model of an infinitely repeated duopoly, comparing scenarios where managers' contracts include RPEs against those where compensation is solely based on the company's own performance metrics. Unlike Salas Fumas (1992) or Asseburg and Hofmann (2008), the presented model considers RPEs that do not involve direct competitors (or use a large index so that the effects of competitors are insignificant). The analysis demonstrates that RPEs increase the gains from collusion and may also make collusive behaviour easier to sustain. The chapter then describes specific conditions under which this holds true and examines how these conditions align with the typical RPE structures implemented in practice. The conclusions from the presented model are similar to two previous works, namely Spagnolo (1999) and Spagnolo (2005). These studies show that multimarket contact and managers' income smoothing increase cartel stability. According to the findings in the theoretical part, RPE awards that do not involve direct competitors may result in the same outcome.

These conclusions underline the necessity for a more critical examination of RPE practices, given their potential to foster anti-competitive behaviours in certain market settings. However, as the model focuses only on one aspect of the RPE awards, namely their strategic effects, the empirical tests of the findings pose significant practical challenges, particularly if based on observational firm-level data. Hence, as a preliminary step, the second part of this chapter outlines the blueprint of an economic experiment to validate its theoretical predictions. The emphasis on the detailed experimental design, rather than immediate results, marks a novel approach and is a deliberate methodological choice. This choice reflects the current academic trend towards preregistration of studies and pre-analysis plans (Bloomfield et al., 2018; Miguel, 2021), underscoring the value of transparency and methodological rigour (Brodeur et al., 2022). This chapter provides a comprehensive plan for the proposed study, encompassing detailed descriptions of the treatments, experimental procedures, clearly defined hypotheses, and a precise analytical approach. Additionally, it includes a power analysis, directly addressing recent concerns about the lack of statistical power in economic studies (Askarov et al., 2023). This comprehensive approach not only adheres to the highest standards of research methodology but also positions this study as a strong contribution to advancing empirical understanding in the field of economic policy and executive compensation analysis.

The theoretical framework in this chapter investigates a currently overlooked aspect of the RPE awards. Although the model serves primarily as an illustration of the potential mechanism, i.e., is not exhaustive in its scope, its implications are nonetheless concerning for anti-trust authorities and policymakers. Confirming these theoretical predictions in a controlled experimental context would ideally pave the way for more comprehensive discussions and empirical analyses. Consequently, the proposed experiment could broaden the collective understanding of the current practices in executive compensation and potentially inform future policy and regulatory decisions in this field.

The rest of the chapter is organised in the following way. Section 4.2 presents a formal framework, identifies conditions where RPE awards are anti-competitive and discusses whether such conditions are observed in practice. Section 4.3 describes related literature and the problems with empirical validation strategies and proposes an experimental design to test the conclusions of the presented model.

4.2 Framework and Practical Implications

4.2.1 Formal Model

Consider a market with two symmetrical companies (firm i and firm j) with symmetrical managers competing in an infinitely repeated setting ($t = 0, 1, 2..$) with a discount factor δ. Each manager chooses some strategic action ($a_{i,t}$) (for example, quantities or prices or advertising budget) at the beginning of each period. The performance of companies i and j is the result of strategic actions and are given by $\pi_i(a_i, a_j)$ and $\pi_j(a_i, a_j)$ (for example, one measure of performance is profits). Besides companies i and j, a large set M (with $i, j \notin M$) of companies compete in other, unrelated markets. At the end of each period, the entire environment is perfectly observable (i.e. the performances of each company). The compensation of the managers can either be standard (w_{st}), i.e., depend on only own-performance in the period t:

$$w_{i,t,st} = f + \gamma\pi_{i,t} \tag{4.1}$$

or be RPE-based (w_{rpe}), i.e., include the RPE award ($F(\pi_{i_t})$):

$$w_{i,t,rpe} = f + \gamma\pi_{i,t} + F(\pi_{i,t}) \tag{4.2}$$

where f represents a fixed salary, γ is the weight of the pay-for-performance incentive, and $F(\pi_{i_t})$ is the RPE component which is awarded after every period t. Without loss of generality, I normalise $f = 0$ and $\gamma = 1$. With regard to the RPE component, there are three assumptions.

Assumption 1 *The relative performance component $F(\pi_{i,t}, \pi_{k,t}, ...)$ is a function that uses some specific set of other companies $k \in K$ as a benchmark peer group. $F(\pi_{i,t})$ is monotonically increasing in the performance of the company i and is monotonically decreasing in the performances of all other companies $k \in K$. The function F can be assumed to be almost everywhere differentiable with*

$$\frac{dF(\pi_{i,t})}{d\pi_{i,t}} > 0, \textit{ for all } i \notin K$$

and

$$\frac{dF(\pi_{i,t})}{d\pi_{k,t}} < 0, \text{ for all } k \in K$$

Assumption 2 *The relative performance component $F(\pi_{i,t})$ does not depend on the performance of the competitor company j, i.e.*

$$\frac{dF(\pi_{i,t})}{d\pi_{j,t}} = 0$$

Assumption 2 implies no strategic interaction between firm i and its direct competitor, firm j, through the RPE bonus. There are two possible ways to achieve this in practice. Firstly, the reference peer group can outright exclude competitors (i.e. $j \notin K$). Then, the assumption is obviously satisfied. Alternatively, the benchmark peer group can include the entire index of firms M (i.e. $K = M \cup j$). In this case, as the number of other firms in the "index" becomes sufficiently large, the impact of one competitor firm becomes insignificant:

$$\lim_{M\to\infty} \frac{dF(\pi_{i,t})}{d\pi_{j,t}} \to 0$$

Assumption 3 *Companies i and j do not influence the performance of other companies outside their industry, and strategic actions of the companies outside the industry do not influence the performance of companies i and j, i.e.*

$$\frac{d\pi_{k,t}}{da_{i,t}} = 0 \text{ and } \frac{d\pi_{i,t}}{da_{k,t}} = 0, \text{ for } i = i, j \text{ and } k \in K \setminus \{i, j\}$$

4.2.2 Comparative Statics

Managers of firms i and j compete in their market by taking actions $(a_{i,t}, a_{j,t})$. I now compare a scenario where both managers are remunerated via w_{st} with a scenario where both are remunerated by w_{rpe}.

First, consider a one-shot interaction (for convenience, the index t is omitted). It is easy to see that under assumptions 1-3, the maximisation problems of the managers do not change when the RPE component is included.

$$\frac{dw_{rpe}}{da_i} = \frac{d\pi_i}{da_i} + \frac{dF(\pi_i)}{d\pi_i}\frac{d\pi_i}{da_i} + \frac{dF(\pi_i)}{d\pi_j}\frac{\pi_j}{da_i} + \sum_{k\in K}\frac{dF(\pi_i)}{d\pi_k}\frac{\pi_k}{da_i} \tag{4.3}$$

The last two terms in equation 4.3 are equal to 0 (assumptions 2 and 3). Therefore, since $\frac{dF(\pi_i)}{d\pi_i} > 0$, maximising w_{rpe} is the same as maximising π_i (i.e. same as maximising w_{st}). It then follows that if the combination (a_i^e, a_i^e) is the Nash Equilibrium of the market under w_{st}, it is also the equilibrium if both managers are compensated via w_{rpe}. Let the companies' performances in the Nash Equilibrium be $\pi_i^e = \pi_j^e = \pi^e$.

Next, consider a repeated interaction. The Nash equilibrium of a static game is also one of the possible equilibrium points in an infinitely repeated game. However, collusion may also be sustainable for some level of the discount factor δ. Similar to the logic in the static game, including the RPE component does not affect the strategies that lead to joint compensation maximisation[4]. If one manager deviates from the cartel agreement in period t, he gains extra benefit for one period. The rival firm reverts to using Nash equilibrium from period $t+1$ onward (grim trigger strategy (Friedman, 1971)). Let π^c be the performance under cartel and π^d be the performance under the deviation, implying $\pi^d > \pi^c > \pi^e$. If the managers collude under the standard scheme, their individual gain from collusion can be calculated as follows:

$$w_{i,st}(\pi^c) - w_{i,st}(\pi^e) = (\pi^c - \pi^e) \tag{4.4}$$

Under the RPE scheme:

$$w_{i,rpe}(\pi^c) - w_{i,rpe}(\pi^e) = \pi^c - \pi^e + F(\pi^c) - F(\pi^e) \tag{4.5}$$

$\pi^c > \pi^e$ also implies $F(\pi^c) > F(\pi^e)$ because of the Assumption 1. Therefore,

Proposition 1 *Including the RPE component increases manager i's gain from collusion.*

From the perspective of the individual manager, collusion is sustainable if the discounted compensation under the cartel is larger than the gain from an individual deviation and subsequent punishment. That is,

$$\frac{w_i(\pi^c)}{1-\delta} > w_i(\pi^d) + \frac{\delta}{1-\delta} w_i(\pi^e)$$

$$w_i(\pi^c) > w_i(\pi^d)(1-\delta) + \delta w_i(\pi^e)$$

$$\frac{w_i(\pi^c) - w_i(\pi^d)}{w_i(\pi^e) - w_i(\pi^d)} > \delta \tag{4.6}$$

If the condition 4.6 is satisfied, i.e., if the discount factor in the market δ is larger than the ratio $\frac{w_i(\pi^c) - w_i(\pi^d)}{w_i(\pi^e) - w_i(\pi^d)}$, collusion is sustainable. In other words, the ratio $\frac{w_i(\pi^c) - w_i(\pi^d)}{w_i(\pi^e) - w_i(\pi^d)}$ defines the critical or minimum discount factor (δ^{min}) that is necessary for collusion to be possible. The critical discount factor is commonly seen as an indicator of how "difficult" collusion is (Fonseca et al., 2018). Using the condition 4.6, the critical discount factors

[4] A common prerequisite for this is the absence of side transfers or possibilities for alternating monopoly.

under different compensation environments are as follows:

$$\delta_{st}^{min} = \frac{w_{st}(\pi^d) - w_{st}(\pi^c)}{w_{st}(\pi^d) - w_{st}(\pi^e)} = \frac{\pi^d - \pi^c}{\pi^d - \pi^e} \tag{4.7}$$

$$\delta_{rpe}^{min} = \frac{w_{rpe}(\pi^d) - w_{rpe}(\pi^c)}{w_{rpe}(\pi^d) - w_{rpe}(\pi^e)} = \frac{\pi^d + F(\pi^d) - \pi^c - F(\pi^c)}{\pi^d + F(\pi^d) - \pi^e - F(\pi^e)} \tag{4.8}$$

Comparing equations 4.7 and 4.8, yields:

$$\delta_{rpe}^{min} < \delta_{st}^{min} \iff (\pi^d - \pi^e)(F(\pi^d) - F(\pi^c)) < (\pi^d - \pi^c)(F(\pi^d) - F(\pi^e)) \tag{4.9}$$

δ_{st}^{min} can be assumed to be the consequence of market characteristics like the nature of competition or product homogeneity. For example, under a standard Cournot duopoly with homogeneous goods $\delta_{min}^{q} = 9/17$, while under Bertrand duopoly, $\delta_{min}^{p} = 0.5$. Assuming the critical discount factor of the market is fixed (δ_{st}^{min}), it follows from Eq. 4.9 that

Proposition 2 *If the condition that* $\frac{F(\pi^d) - F(\pi^c)}{F(\pi^d) - F(\pi^e)} < \delta_{st}^{min}$ *is satisfied, collusion under RPE is easier to sustain.*

Note that even if only one manager is compensated by the RPE, the decrease in one discount factor may be sufficient to make collusion more likely. Based on the balanced temptation approach (Friedman, 1971), the manager with lower critical δ can sacrifice a small amount of performance of his firm (i.e. split the market unequally) and increase the benefit of cooperation to the other manager (similar to the model in Guigou and de Lamirande (2015)).

4.2.3 Specifications of the RPE Component

Proposition 1 is robust under fairly general assumptions, but Proposition 2 depends on the specification of $F(\pi_i)$ and the combination $\pi^d > \pi^c > \pi^e$ that defines critical minimum discount factor. Broadly, there are three possible scenarios:

Corollary 1 *If the point* $(\pi^c, F(\pi^c))$ *lies on the line connecting the points* $(\pi^d, F(\pi^d))$ *and* $(\pi^e, F(\pi^e))$*, the RPE component does not have an effect on critical minimum discount factors.*

Corollary 2 *If the point* $(\pi^c, F(\pi^c))$ *lies above the line connecting the points* $(\pi^d, F(\pi^d))$ *and* $(\pi^e, F(\pi^e))$*, the RPE component makes collusion easier to sustain.*

Corollary 3 *If the point* $(\pi^c, F(\pi^c))$ *lies below the line connecting the points* $(\pi^d, F(\pi^d))$ *and* $(\pi^e, F(\pi^e))$*, the RPE component makes collusion harder to sustain.*

For the proofs, see Appendix 4.A. Corollaries 1-3 do not require the function $F(\pi_i)$ to be continuous, or only concave, or only convex. However, if the function $F(\pi_i)$ is linear and continuous on the interval $[\pi_e, \pi_d]$, then the condition for Corollary 1 is satisfied. Similarly, if the function $F(\pi_i)$ is strictly concave (convex) on the interval $[\pi^e, \pi^d]$, then Corollary 2 (3) is satisfied. The usefulness of the general approach in Corollaries 1-3 is that one can analyse a wider range of specification of $F(\pi_i)$.

4.2.4 Practical Implications

Proposition 1 only requires the RPE component to be increasing in performance of the company π_i. However, the gain from collusion alone may not be problematic for competition authorities unless the resulting collusion is also more stable. Therefore, the critical question is whether the condition in Corollary 2 is satisfied in the contracts used in practice.

De Angelis and Grinstein (2019) and Bizjak et al. (2022) report that RPEs usually take the form of a rank-order tournament (similar to Lazear and Rosen (1981)). In this interpretation, the owners rank their company's performance measure (for example, shareholder return or profits) against the performance of the set of peers or an index[5]. The manager is rewarded with an additional bonus if the performance is above a certain rank in the tournament.

First, consider the simplest version of such a tournament. Suppose π_i is the performance of the manager of firm i. If the manager i's compensation includes an own-performance element, then without the RPE component, market conditions in his industry result in some competitive equilibrium outcome (π^e), collusive outcome (π^c) and deviation outcome (π^d), with $\pi^e < \pi^c < \pi^d$. This combination of market outcomes defines some level of critical minimum discount factor $\delta^{st}_{min} < 1$.

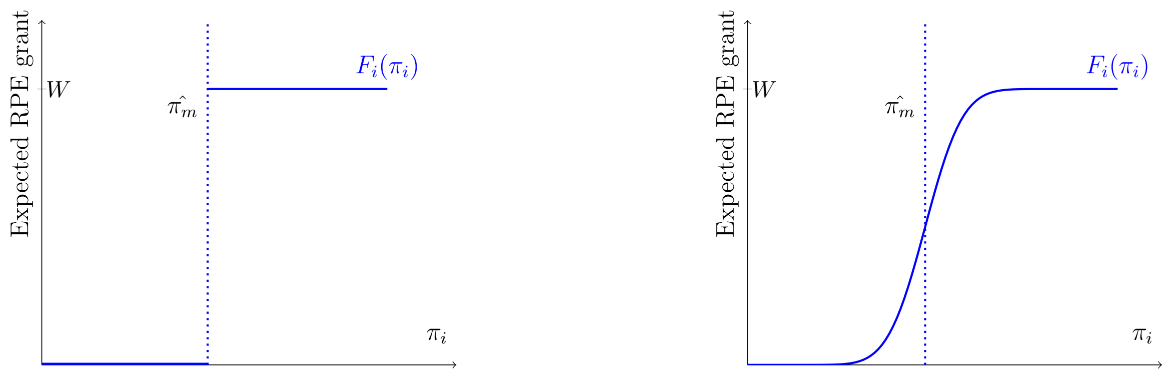
At the end of each period t, the shareholders of firm i rank the performances of their company against $k \in K$ companies in other industries or a broad index $\{\pi_1, \pi_2, ...\pi_k, \pi_i\}$. The manager of their firm i is rewarded with some proportion of the own-performance metric and fixed prize (W) if his performance is above the median of that group. Let the performance of the median company be π_m. Then, the RPE component can be represented in the following way:

$$F_{i,t}(\pi_{i,t}) = \begin{cases} W & \text{if } \pi_{i,t} > \pi_m \\ 0 & \text{otherwise.} \end{cases}$$

The performance of the median company can be assumed to be either perfectly observable

[5]For examples of such contracts, see 8-k forms of Tim Cook (Apple Inc.) or Sundar Pichai (Alphabet Inc.) provided in Appendix 4.B.

by the manager of firm i ($\pi_m = \hat{\pi_m}$) or be imperfectly observable[6] (e.g., $\pi_m \sim N(\hat{\pi_m}, \sigma_m^2)$). The expected value of the RPE award as a function of performance is illustrated in Figures 4.2.1a-4.2.1b, where $\hat{\pi_m}$ (indicated by the dotted blue line) is the performance of the median firm.



(a) Perfectly Observable Performance (b) Imperfectly Observable Performance

Figure 4.2.1: Different Functional Forms

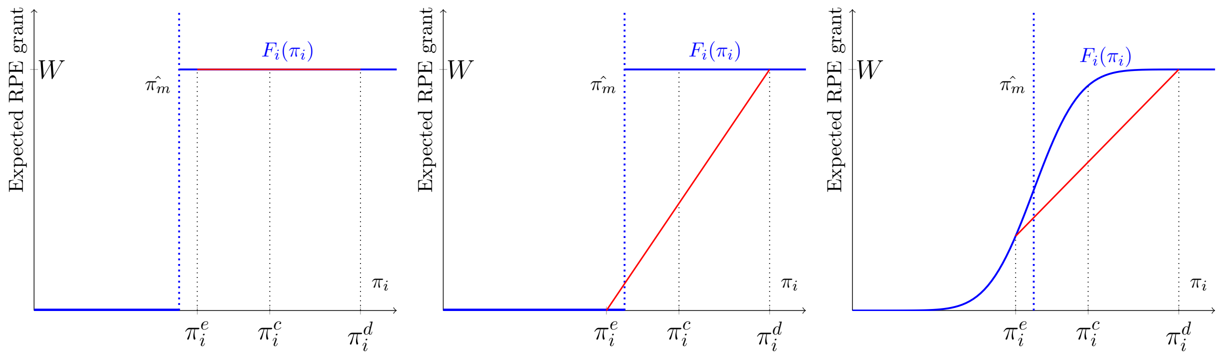
First, consider the perfectly observable performance case. If all $\pi_i^d > \pi_i^c > \pi_i^e$ are on the same line segment, the critical minimum discount factor does not change (Corollary 1). For example, suppose $\pi_i^d > \pi_i^c > \pi_i^e > \hat{\pi_m}$, as demonstrated in Figure 4.2.2a. In this case, the three market outcomes result in the same level of expected RPE grant, i.e., lie on the line segment of $F_i(\pi_i)$ to the right of $\hat{\pi_m}$. Thus, points $(\pi_i^e, F_i(\pi_i^e))$,$(\pi_i^c, F_i(\pi_i^c))$, and $(\pi_i^d, F_i(\pi_i^d))$ lie on the same line and the condition in Corollary 1 is satisfied. However, if $\pi_i^d > \pi_i^c > \hat{\pi_m} > \pi_i^e$ (as shown in Fig. 4.2.2b), then the point $(\pi_i^c, F_i(\pi_i^c))$ lies above the line (depicted in red) connecting the points $(\pi_i^e, F_i(\pi_i^e))$, and $(\pi_i^d, F_i(\pi_i^d))$. This implies that $F(\pi^d) = F(\pi^c) = W > F(\pi^e) = 0$, Corollary 2 is satisfied and the collusion is more sustainable. On the other hand, if $\pi_i^d > \hat{\pi_m} > \pi_i^c > \pi_i^e$, the collusion becomes less sustainable.

When the performance is not fully observable, the expected value of the grant is $F_i(\pi_i) = W * Pr(\pi_i > \hat{\pi_m})$ which depends on the cumulative distribution function (cdf) of π_m. However, any cumulative distribution function $F : \mathbb{R} \to [0, 1]$ would have intervals where the condition in Corollary 2 is satisfied[7]. In the case of the normal cdf, the function $F_i(\pi_i)$ is concave to the right of $\hat{\pi_m}$. Therefore, for some combination of $\pi_i^d > \pi_i^c > \pi_i^e$, tournament structure with imperfectly observable performance would result in more stable collusion. One example is illustrated in Figure 4.2.2c.

Although the provided examples may initially seem somewhat limited in scope, their underlying structure corresponds to actual contractual frameworks, such as that of Sundar

[6]For example, if the manager of firm i can only guess the performance of other companies when making his strategic action.

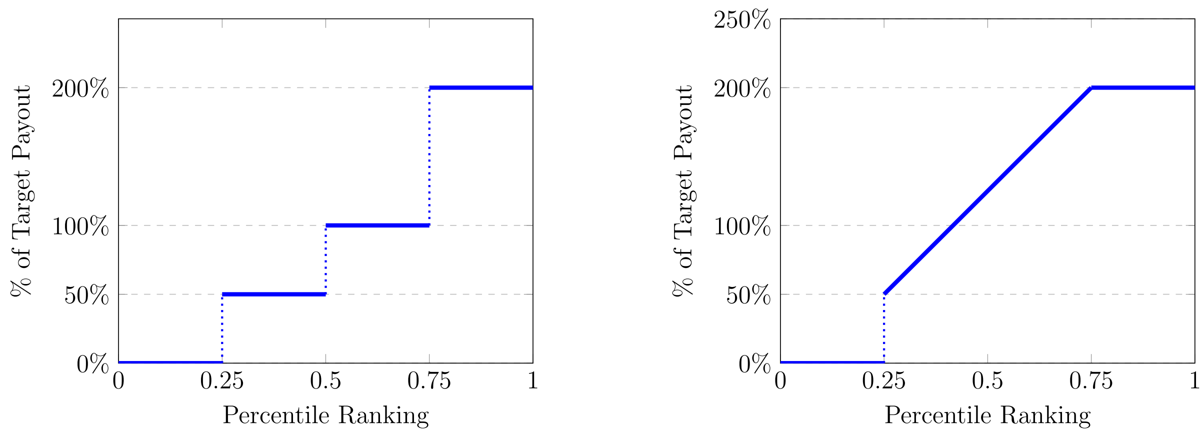
[7]This follows directly from the definition of the cumulative distribution function. As any cdf is non-decreasing and bounded, it cannot be convex on the entire domain $\mathbb{R}$. See the proof of Proposition 3 in Appendix 4.A.



(a) (b) (c)

Figure 4.2.2: Illustrative Examples

Pichai (Alphabet Inc. (2022) in Appendix 4.B). Extending this setting to a more general approach, studies by De Angelis and Grinstein (2019) and Ma et al. (2021) describe a typical RPE award scheme. The scheme consists of three different levels: a baseline payout for minimum performance levels, an expected payout associated with achieving standard performance targets, and a capped payout for exceptionally high-performance levels (Do et al., 2022). Figure 4.2.3 visualises[8] the relationship between payout value and performance (as the rank relative to peer performance).



(a) Stepwise RPE Scheme (b) Linear Interpolation RPE Scheme

Figure 4.2.3: Illustrations of Compensation Structures

When the firm's performance is in the lowest 25th percentile compared to RPE peers, managers are ineligible for bonuses or shares. Beyond this threshold, compensation increases progressively with each rank. Some RPE compensation awards allow for interpolation between the minimum performance and maximum performance (Fig. 4.2.3b), while others employ a clear step-wise structure (Fig. 4.2.3a). The maximum payout is capped for performances within the top 25th percentile. Both payout structures contain

[8] Similar representations can be found in Gong et al. (2011), De Angelis and Grinstein (2019) or Do et al. (2022).

intervals where Corollary 2 is satisfied. In the case of step-wise payoffs, collusion is easier to sustain if collusive performance (π^c) and deviation performance (π^d) fall onto the same line segment while equilibrium performance doesn't. In the case of linear interpolation (Fig. 4.2.3b), if the performance of the firm under competitive equilibrium (π^e) falls above the bottom 25 percentile, then including such RPE in executive compensation is either neutral with respect to collusion stability (on the linear interval) or anti-competitive due to the concave interval.

As discussed in Do et al. (2022), most RPE payout structures are convex in the lower half and around the target performance but concave in the upper half. Furthermore, the maximum payout is usually capped with respect to performance (i.e. if the firm outperforms the 75th percentile of its peers). Broadly,

Proposition 3 *If the RPE component $F(\pi_i)$ is bounded from above, there exists an interval $\pi_i \in [\pi^e, \pi^d]$ such that the condition in Corollary 2 is satisfied.*

For the proof, see Appendix 4.A. In other words, commonly used RPE awards, i.e., that either use tournament structure or are in some other way capped with respect to performance, contain intervals where collusion is easier to sustain.

Regions, where the condition in Corollary 2 is satisfied, depend on the exact values of $\pi_i^d, \pi_i^c, \pi_i^e$ and the performance of the median firm $\hat{\pi_m}$. If the peer group is constructed in a way that the benchmark companies are expected to underperform, then it is more likely that the collusion would be more stable under the RPE metric. Using underperforming peers puts the focal firm's manager in the upper half of the payout structure, which is usually concave (Do et al., 2022). Gong et al. (2011) and Bizjak et al. (2022) both report that it is common that RPE firms are more likely to select peers who are expected to perform poorly[9].

The extent to which including RPE awards changes the critical minimum discount factor depends on the size of the RPE bonus compared to the own-performance sensitivity parameter (indicated by W and γ, respectively). In an extreme case where γ is close to 0 or when the size of the payout is relatively large, the impact of the RPE award on the critical discount factor would become larger (this follows from Eq. 4.8). For example, consider the perfectly observable tournament setting and $\pi_i^d > \pi_i^c > \hat{\pi_m} > \pi_i^e$. Then,

$$\delta^{min} = \frac{w_{rpe}(\pi^d) - w_{rpe}(\pi^c)}{w_{rpe}(\pi^d) - w_{rpe}(\pi^e)} = \frac{\pi^d + F(\pi^d) - \pi^c - F(\pi^c)}{\pi^d + F(\pi^d) - \pi^e - F(\pi^e)} =$$
$$= \frac{\pi^d + \cancel{W} - \pi^c - \cancel{W}}{\pi^d + W - \pi^e - 0}$$

Hence,

[9]One potential explanation for such behaviour is based on the rent-extractions hypothesis (Bebchuk et al., 2002). See Edmans et al. (2017) for a review and Dikolli et al. (2017) for the model on CEO power influencing the choice of the RPE peer group.

$$\lim_{W \to \infty} \delta^{min} \to 0 \tag{4.10}$$

Do et al. (2022) observe in their study of major firms that attaining top-tier performance results in a significant increase in CEO compensation, amounting to $4.2 million bonus. This increment is notable as it forms a substantial part of the $7.3 million median total compensation for CEOs in their sample. Put differently, the effects of the RPE on the stability of collusion can be further amplified by the size of the payout.

4.2.5 Discussion

The presented model isolates one aspect of RPE awards[10] - its main objective is to illustrate the strategic consequences of the RPE awards that exclude competitors. The intuition behind the results is very straightforward. Once an additional structure (e.g., tournament) is imposed on the managers by the RPE contracts, the managers benefit from cooperating at the market level, as if forming a team against all other companies in the relative performance benchmark groups. If the RPE component is concave (or has concave intervals) with respect to performance, collusion under RPEs may become easier to sustain. Thus, at least for some companies, RPEs have anti-competitive effects. This conclusion contrasts the popular opinion that RPE bonuses are pro-competitive or, at minimum, neutral in their effects on collusive tendencies (Walker, 2019).

These theoretical predictions are of immediate concern to antitrust authorities as they align with current practices in RPE-based remuneration. As reported by De Angelis and Grinstein (2020), 88 per cent of companies use rank-order tournaments with concave intervals. Analyses by Albuquerque (2009), Gong et al. (2011), and Bizjak et al. (2022) report significant heterogeneity in the selection of benchmark peer groups used in such tournaments. For example, De Angelis and Grinstein (2020) show that a third of all peer group companies do not belong to the same 2-digit standard industrial classification (SIC) code as the respective firm. Furthermore, even if the chosen peer group contains direct competitors, the size of the peer group may be large enough[11] for anti-competitive effects to be dominant (i.e. bringing Assumption 2 closer to being satisfied). Ma et al. (2021) and Bizjak et al. (2022) show that a significant amount of firms use either a global index (e.g., S&P 500) or an industry-specific index (See Table 4.C.1, Appendix 4.C). Furthermore, Ma et al. (2021) mention that compensation consultants often suggest using a broad market index, potentially exacerbating the problem.

[10] One possible extension is to include costly effort levels of the manager, similar to Salas Fumas (1992) or Asseburg and Hofmann (2008). See Appendix 4.D for a brief note.

[11] Ma et al. (2021) reports that the average peer group size is around 18 companies. Therefore, for concentrated industries, non-competitor firms outnumber direct competitors in the reference set.

4.3 Empirical Validation

The theoretical model presented in Section 4.2 demonstrates how RPE awards without competitors can induce collusive tendencies. Several recent[12] works have examined the relationship between RPE awards, peer group composition, and market dynamics. However, these works focus primarily on the RPEs that include direct competitors.

Feichter et al. (2022) explore how peer group overlap influences competitive behaviour. Peer group overlap refers to the scenarios where two firms select each other as part of their respective RPE reference groups. The data suggests that peer overlap is more likely to happen between firms in the same industry, i.e., direct competitors (Feichter et al., 2022, Table 4 Panel D). As complete information about the firm's strategic choices is often unavailable, the authors measure competitive aggressiveness as the volume and complexity of strategic actions based on the publicly available articles in business journals. The analysis is mostly based on observational data[13]. The results suggest that a higher level of peer group overlap in concentrated markets increases competitive aggressiveness.

The conclusion in Feichter et al. (2022) is congruent with the "sabotage" hypothesis. According to the sabotage hypothesis, executive managers are encouraged to use aggressive competitive strategies when the RPE benchmark includes direct competitors. Based on this conjecture, firm owners may be reluctant to construct the RPE peer group in this manner. However, if the firms establish a collusive agreement, the owners may enjoy the benefits of RPEs without their adverse effects on the product market strategies. By examining the relationship between explicit cartels and RPEs that include direct competitors, Bloomfield et al. (2023) support this conjecture. Their analysis shows that cartel members are more likely to use RPEs and select competitors as part of the RPE reference group. The firms are also more likely to drop such RPEs when the cartel is dissolved.

Both Feichter et al. (2022) and Bloomfield et al. (2023) assume RPEs do not significantly affect the market strategies if the reference peer group excludes competitors[14]. Furthermore, as noted in Section 4.2.4, important conditions for the collusion to be more

[12]Early research primarily focused on explaining the "RPE puzzle", i.e., the observed paucity of relative performance evaluation practices in executive compensation. Prior to 2006, the exact details of the contracts or the composition of the peer groups were not publicly available. Thus, previous studies used a regression-based approach to estimate the use of RPE metrics. See Kabitz (2017) for a survey. More recent works use explicitly disclosed incentives and peer groups, e.g., Gong et al. (2011), Angelis and Grinstein (2019), Do et al. (2022) and Bloomfield et al. (2023).

[13]The study also uses a difference-in-difference approach, exploiting the fact that if one of the peers adds the focal firm to their RPE metric, the focal firm receives a new member of peer group overlap. The authors argue it is "plausible to assume that the focal firm cannot manipulate its peers' peer selection". However, according to the strategic delegation literature, this choice of the peer firm can be a direct retaliation. Additionally, as noted in Lieberman and Asaba (2006), firms in the same industry often imitate each other.

[14]Bloomfield et al. (2023) benchmark their results against firms using generic RPE (those using a broad index), whereas Feichter et al. (2022) benchmark their results against firms with RPE but no peer group overlap.

likely include not only the absence of direct competitors in the RPE peer group but also the *shape* of the award (i.e., the function imposed by a tournament setting). Do et al. (2022) is the only recent work that analyses the effects of tournament structure induced by the RPE bonuses on corporate strategy[15]. In other words, the concerns highlighted in the theoretical part of this chapter are largely overlooked in the current empirical literature[16].

Generally, establishing the causal effects of managerial compensation schemes from observational firm-level data is fraught with difficulties. As noted in Edmans et al. (2017), "there are almost no instrumental variables or natural experiments that create as good-as-random variation in compensation contracts" (Edmans et al., 2017, p.387). Decisions about whether to use RPE awards and how to compose the benchmark peer group are highly endogenous and depend on many other variables, e.g., market concentration (Bloomfield et al., 2023), type of competition (Vrettos, 2013) or CEO power (Dikolli et al., 2017). Hence, estimating the effects of RPE awards on market dynamics would inadvertently suffer from selection bias. Validating the theoretical predictions of this chapter poses further challenges, as the proposed model focuses on the strategic aspect of the RPE awards and serves primarily as the illustration of a potential mechanism. The firm's performance and competitive stance would depend on the CEOs' effort and ability, which, in turn, would also be affected by the RPE-based contract scheme. In other words, isolating the strategic effects of the RPE-based bonuses using observational data would be problematic. Furthermore, the effects of the RPE awards on collusive tendencies would also depend on the type of own-performance bonuses (Spagnolo, 2000; Lambertini and Trombetta, 2002) and would require a complete description of the contract terms, including performance targets and personal holdings of executive managers[17]. This data is often not publicly available. Lastly, detecting collusive behaviours introduces additional complications in the analyses, given that such actions are frequently clandestine and illegal under antitrust laws.

Given these constraints, this chapter proposes a lab experiment to validate its theoretical conclusions. Unlike observational data, a controlled experimental environment provides a way to test theory predictions and establish an unambiguous causal relationship (Normann and Ruffle, 2011). In the context of the proposed model, experimental analysis avoids problems with observational firm-level data due to exogenous contract allocation and perfect observability of compensation contracts and market strategies. Ul-

[15] More specifically, Do et al. (2022) look at corporate risk-taking and analyse long-term RPE incentives. The authors report that if a firm performs poorly during the initial part of the evaluation period, it takes more risks for the remainder of the period.

[16] Findings in Feichter et al. (2022) could also be interpreted as RPE without overlap resulting in less competitive aggression (i.e., partial collusion in line with predictions in Section 4.2). However, the authors do not estimate competitive aggression for non-RPE firms.

[17] Managers can use available financial instruments to self-hedge against risk (Diser and Hofmann, 2018), which would have similar implications as the explicit incentive provided by the RPE contract.

timately, validating theoretical predictions in a simplified environment would serve as an invitation for a closer examination of the current practices in executive compensation.

4.3.1 Experimental Design Proposal

The first step in experimental design is to define a clear research objective. In this case, the experiment's aim follows directly from theoretical considerations described in the main body of the paper and reports of the contracts used in practice. The research question can be summarised in the following way:

Do the RPEs with a tournament structure and without direct competitors increase collusive tendencies?

Answering this research question necessitates an experimental environment that aligns with the Assumptions 1-3 made in the theoretical model. The model is robust with respect to the type of competition. Consider a market environment where the following static game is repeated over an infinite horizon with a constant discount rate δ.

1. $2N$ firms compete in N symmetric quantity-setting duopoly markets, i.e. Cournot duopolies. Let i and j denote any two companies that compete against each other in one market. The firms face inverse demand $P = a - q_i - q_j$ and have constant marginal costs c. Each company's profits in the market are $\pi_i = (a - c - q_i - q_j)q_i$.

2. In each market, decisions about the quantity (q_i and q_j) are made by the managers of the firms in that market.

3. Each manager is compensated by either a contract that depends only on absolute performance evaluation (w_i^{ape}):
$$w_i^{ape} = \pi_i$$
or includes an RPE component (w_i^{rpe}):
$$w_i^{rpe} = \pi_i + RPE$$
where π_i is the profits of company i and RPE_i is the relative performance component.

4. The RPE component is a simple rank-order tournament of $2N - 1$ firms, i.e. all $2N$ firms excluding direct competitor of the firm i. The manager receives an extra bonus W if his company's performance π_i is median or above compared to all other firms.

$$RPE_i = \begin{cases} W & \text{if } \pi_i \text{ ranks in the top } N \text{ companies excluding the competitor company } j \\ 0 & \text{otherwise.} \end{cases}$$

Ties in the ranking are broken randomly.

5. Individual profits of each company are observable after each period (to every manager). Furthermore, each individual manager knows his contract and whether he has received the bonus at the end of each period.

The basic structure of the RPE component corresponds to the rank-order tournaments observed in practice. The RPE component is non-decreasing in profits (π_i), satisfying Assumption 1. The RPE component is a rank-order tournament that excludes direct competitors, satisfying Assumption 2. Lastly, any two firms (say, i and j) compete in isolated industries. Consequently, their actions cannot change the profits of other firms, and other firms' actions cannot change the profits of firms i and j, satisfying assumption 3.

Suppose there are three conditions:

- **Condition 1 (Control - C):**
  - In this condition, none of the managers in the market are under Relative Performance Evaluation (RPE) contracts. Instead, the compensation for all $2N$ managers is solely based on their respective company's performance (w_i^{ape}).
- **Condition 2 (Treatment Full - TF):**
  - In this condition, all managers ($2N$) are compensated with an RPE contract (w_i^{rpe}).
- **Condition 3 (Treatment Half - TH):**
  - In this condition, half of the managers (N out of $2N$) have compensation contracts that include an RPE component (w_i^{rpe}). In the simplest setting, the contract allocation is random on the individual level but is fixed on the market level. In other words, either both managers in the market are compensated with the RPE contract, or both managers are compensated with the APE contract. This pattern ensures comparability with the other conditions.

Theoretical Predictions

Note that neither the static Nash Equilibrium nor collusive quantity choices change in the above setting if the RPE component is added to the managers' compensation. However, a broad range of possible collusive strategies can be sustained if the game is played over an infinite horizon.

First, consider Condition 1, where each individual market is a standard Cournot duopoly. In this scenario, collusion can be sustained if $\delta > \delta_{ape}^{min} = 9/17$[18].

[18] Using a grim-trigger strategy. See Feuerstein (2005a) for a review and comments by Kuhn (2005). Cabral (2005) and Feuerstein (2005b) for a discussion.

Next, consider Conditions 2 and 3, where some of the managers are compensated with an RPE-based contract. The RPE component is structured as a rank-order tournament. Without loss of generality, focus on the decisions of an individual manager with an RPE-based contract. In the worst scenario (i.e., when every other $(N-1)$ market is colluding), his critical minimum discount factor will be lower than the critical minimum discount factor in a standard Cournot duopoly. Proposition 2 states that $\delta_{ape}^{min} > \delta_{rpe}^{min}$ if

$$\frac{F(\pi^d) - F(\pi^c)}{F(\pi^d) - F(\pi^e)} < \delta_{ape}^{min} = \frac{9}{17}$$

The equilibrium profits of π^e would have no chance of winning W since all other $N-1$ markets collude. Collusive payoff π^c would result in a tie with other colluding firms. The expected value of the prize would be $\frac{WN}{2N-1}$. Individual deviation payoff π^d would then put the manager's company first in the rank-order tournament, resulting in the prize of W. Therefore,

$$\frac{F(\pi^d) - F(\pi^c)}{F(\pi^d) - F(\pi^e)} = \frac{W - \frac{WN}{2N-1}}{W - 0} = \frac{N-1}{2N-1} < \frac{1}{2} < \delta_{ape}^{min}$$

If some markets do not collude, then the critical minimum discount under RPE becomes even lower as $\frac{WN}{2N-1}$ would be larger. This would imply that the effect on the critical minimum discount factor would be more pronounced in Condition 3, as the markets with only APE contracts would find it harder to sustain collusion.

Testable Hypotheses

A direct implication of the theoretical predictions is that average observed quantities are lower in the markets where the RPE component is present. The decrease in critical discount factors is generally associated with an increase in the rates of cooperation. Thus, more markets would collude (i.e., choose lower quantities) if the critical minimum discount factor is lower[19]. The first testable hypothesis can be summarised in the following way:

Hypothesis 1 *The average observed quantities in the markets in Condition 1 (i.e., where no managers are compensated with RPE contracts) would be higher than the average observed quantities in markets in Conditions 2 and 3 (i.e. when, at least in some markets, managers are compensated with the RPE contract).*

[19]See Blonski et al. (2011) and Blonski and Spagnolo (2015) for a discussion on critical minimum discount factors.

Additionally, the theoretical prediction can be interpreted in terms of the likelihood of observing partial collusion markets. A partially collusive market is any market with total output below the static Nash Equilibrium (Haan et al., 2009). Consequently,

Hypothesis 2 *The likelihood of observing partially collusive markets in Condition 1 (i.e., where no managers are compensated with RPE contracts) would be lower than the likelihood of observing partially collusive markets in Conditions 2 and 3 (i.e. when, at least in some markets, managers are compensated with the RPE contract).*

Experimental Procedures

Conducting an experiment in an infinitely repeated setting is not feasible in a lab setting. The standard approach for simulating such an environment is based on a random termination procedure as suggested by Roth and Murnighan (1978). In other words, participants engage in *indefinitely* repeated games that end in a finite time, with the exact time of the end unknown to the players. This approach is implemented in Chapter 3.

Based on the testable hypotheses, the proposed design contains the following steps for an experimental session of size $2N$:

1. **Introduction to the environment**:
    - Participants get the full description of the market environment, including the number of firms in the market, the inverse demand function and the profit function of each company.
    - Participants act as managers of their respective firms. To help participants with their decisions, they are given a profit calculator.
    - Participants receive information about the random termination procedure.
2. **Practice round (not payoff relevant)**:
    - Participants are randomly matched in Duopoly markets and play one practice supergame under w_{ape}. The matching is constant during the duration of the supergame.
    - At the beginning of each period, each participant submits his quantity choice.
    - After each period, participants receive information about the competitor's action and the resulting profits of both companies in their market.
    - Additionally, after each period, participants receive information about the profits (but not actions) of all other $2N-2$ companies.
3. **Decision stage (payoff relevant)**:

- Depending on whether the session is under Condition 1, 2 or 3, the participants are assigned either w_{ape} or w_{rpe}. In Condition 1, every participant is compensated with w_{ape}. In Condition 2, every participant is compensated with w_{rpe}. In Condition 3, half of the participants are compensated with w_{ape} and half with w_{rpe}. The assigned contract is constant for the duration of the session.
- Participants under the w_{rpe} contract receive full information about the nature of the RPE component. At the end of each period, if their company's profits are in the top N companies (excluding their direct competitor), they receive an additional bonus of W.
- The participants are matched with a new participant. They then make repeated decisions until the end of the supergame.
- Throughout the decision stage, participants receive the same information as during the practice round (i.e., the actions of their competitors and the profits of each company in the session).

4. **Payment**:
   - After the conclusion of the decision stage, the participants are paid cumulative compensation (i.e., the sum of per period payoffs) in accordance with their assigned contract. The compensation is bounded from below. In other words, participants cannot earn negative total payoff (but can earn negative compensation in one period).

Described experimental procedures imply a complete between-subject design. Additionally, it is possible to run multiple supergames during the decision stage to increase the number of observations and the statistical power of the analysis. As market parameters, I suggest using $a = 100$ and $c = 0$ to ensure comparability to the setting described in Chapter 3. Based on these parameters, the market conditions yield the following:

Static equilibrium quantities: $q_i^e = q_j^e = 33$

Static Equilibrium Profits: $\pi_i^e = \pi_j^e = 1122$

Collusive Quantities: $q_i^c = q_j^c = 25$

Collusive Profits: $\pi_i^c = \pi_j^c = 1250$

Similar to Chapter 3, the probability of continuing the supergame at each round is $p = 90\%$. The average length of the supergame is 10. The value of the per period prize is $W = 300$. The maximum average compensation of an individual participant would be:

Collusive Compensation: 1250

RPE component (assuming half of the participants receive the prize): 150

Total (based on the average supergame duration): 14000

Assuming the exchange rate of 1000 Experimental points = 1 EUR, the maximum per person cost is estimated to be 14 euros, excluding the participation fee. Based on the data from the experiment in Chapter 3, the actual costs would be lower due to more competitive outcomes.

4.3.2 Notes on Practical Implementation

The initial exploratory step could be performed by running Condition 1 with either Condition 2 or Condition 3. Although Condition 2 results in more markets with managers incentivised by the RPE contracts, it can be argued that the collusive effects would be more pronounced in Condition 3.

Suppose Conditions 1 and 2 are run as a preliminary study. For the tests of the Hypothesis 1, I suggest using a linear mixed model of the following form:

$$Q_{it} = \beta_0 + \beta_1 RPE_i + Period_t + \eta_i + \epsilon_{it} \tag{4.11}$$

Where Q_{it} is the quantity observed in the market i in period t, RPE_i is a dichotomous variable taking the value 1 if the market had both managers under the RPE contract and 0 otherwise, $Period_t$ is a dummy variable for each period, η_i is a market-specific random effect (assumed to be independently and normally distributed) and ϵ_{it} is a period-specific error term.

The proposed experimental procedures imply a complete between-subject design where each participant plays exactly one market (beyond the practice round). For $2N$ participants, the proposed procedures yield N market observations or $10N$ period observations. Figure 4.3.1 illustrates the power of this approach based on an equal split between conditions 1 and 2.

The power estimations in Figure 4.3.1 are computed using 1000 simulations for each combination of the treatment effect (i.e., β_1) and the number of markets (N). The power is calculated as the proportion of 1000 simulations that correctly rejected the null hypotheses ($H_0 : \beta_1 = 0$) at a 5 per cent significance level after running the proposed regression (Eq. 4.11). The data was generated in R using the “simstudy” package (Goldfeld and Wujciak-Jens, 2020), and regressions were run using the “lme4” package (Bates et al., 2015).

The simulations used the following data-generating processes. The average observed quantity without RPEs (β_0 in the regression equation) is assumed to be 63. This choice corresponds to the mean of the market quantities observed in Chapter 3 under the same market conditions. The market-specific random effect is assumed to be $\eta_i \sim \mathcal{N}(0, 11^2)$ and period specific error to be $\epsilon_{it} \sim \mathcal{N}(0, 5^2)$. Combined, these effects are close to the variance of quantities observed in Chapter 3. The chosen parameters are much more conservative

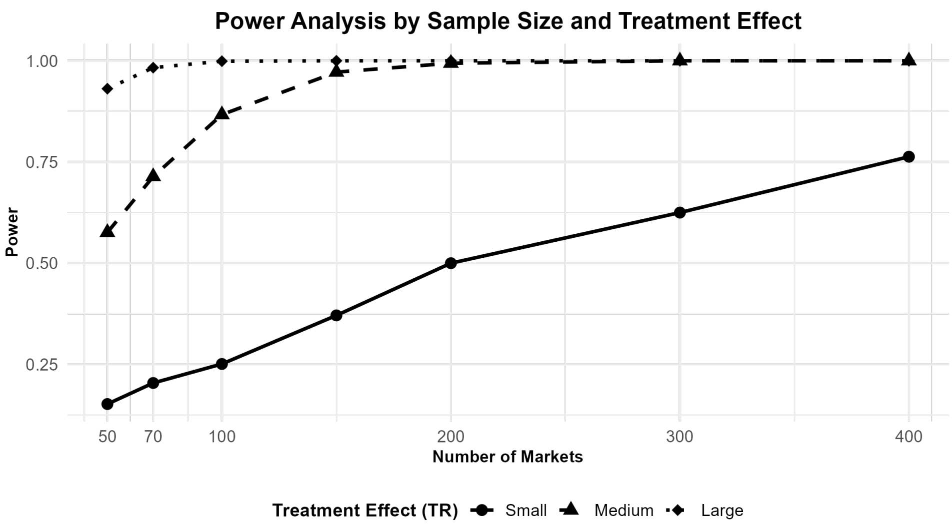


Figure 4.3.1: Power Analysis

than those described, for example, in Huck et al. (2004b), who report a standard deviation of around 7 in duopoly Cournot markets with similar parameters. The treatment effect of the RPE component (β_1) is assumed to be -3 (Small), -7 (Medium), and -11 (Large). If all markets where both managers' compensations involve the RPE component collude perfectly, the observed effect would be -13.

Figure 4.3.1 suggests that to have an 80 per cent chance of detecting the medium-size effect of RPE bonus structure, the experiment would require around 80 markets (800 per-period observations) or 160 participants. If the participants play more supergames (i.e., participants are re-matched after the market concludes) or the supergames last longer than ten periods (i.e., the probability of continuing the supergame at each round is $p > 90\%$), the number of participants could be reduced.

4.3.3 Discussion

The proposed experiment is tailored to test the strategic implications of the RPE awards without competitors. The structure of the RPE awards in the proposed framework mirrors the contracts commonly observed in practice. However, the suggested design makes several steps to simplify the experimental environment. The firms and contract allocations are symmetric, and the markets are quantity-setting duopolies. This specific context might limit the applicability of the experimental results to different industry settings or broader market conditions, e.g., asymmetric contract allocation, a larger number of firms, price competition or heterogeneous goods. Although the suggested design may reduce the study's external validity, it allows for establishing an unequivocal causal relationship between RPE awards and collusive tendencies. Demonstrating this link within a simplified setting is a fundamental step towards understanding the full range of effects of the currently used compensation schemes.

The outlined experiment aims to contribute to several strands of literature. Most importantly, the proposed experiment offers an exciting opportunity to test a novel perspective on RPE awards, thus adding to a large body of work on tacit collusion and market competition (Engel, 2015). If the predictions are validated, the experimental results can have immediate implications for policymakers, as the concerns highlighted in the theoretical part of this chapter are unaddressed in the literature. Additionally, the RPE awards in the proposed experiment employ a rank-order tournament. However, managers under RPE-based contracts do not necessarily compete against other managers who are in the reference peer group (De Angelis and Grinstein, 2020). Furthermore, their compensation and performance depend not only on their effort but also on their strategic choices. This strategic aspect is not explored in the current experimental literature on tournaments and contests (Dechenaux et al., 2014).

The experimental design can also be modified to accommodate further research questions. For example, the RPE component can include direct competitors, thereby checking whether the pro-competitive effects of the RPEs are sufficient to nullify incentives to collude. Additionally, if the RPE component is replaced with a fixed target instead[20], the experiment can be then interpreted as a test of the income-smoothing hypothesis in Spagnolo (2005). Lastly, running Condition 3 also offers opportunities for additional analysis. Since the participants can see the profits of other companies (due to perfect observability) in all conditions, if managers under the RPE contracts do indeed collude more often, managers under APE may change their behaviour. The latter could be seen as a side effect of the RPE contracts on managers with APE contracts.

4.4 Conclusion

This chapter explores the effects of RPE bonuses that do not include direct competitors on market dynamics. The theoretical analysis demonstrates that depending on the payout structure, RPE awards constructed in this manner may encourage collusion and make it easier to sustain. Compensation contracts in use today often contain intervals where that is the case, e.g., those employing a tournament-like structure. These concerns are predominantly overlooked in the existing literature on RPE-based bonuses. Thus, this chapter proposes an experimental design as a preliminary step in validating its theoretical predictions. Ultimately, establishing a clear causal link in a controlled environment would serve as a call for a more critical examination of the current practices in executive compensation.

[20] Murphy (2000) reports that own performance bonuses often have the same structure as the RPEs in Figure 4.2.3b. In other words, they are usually capped with respect to performance, thereby inducing the same concave function on the managers.

Appendix 4.A: Calculations and Proofs

Proof of Corollary 1

Suppose $(\pi^c, F(\pi^c))$ lies on the line connecting the points $(\pi^d, F(\pi^d))$ and $(\pi^e, F(\pi^e))$, and $\pi^d > \pi^c > \pi^e$. It then follows that for some $\gamma \in (0,1)$, such that $\pi^c = (1-\gamma)\pi^d + \gamma\pi^e$, it also holds true that $F(\pi^c) = (1-\gamma)F(\pi^d) + \gamma F(\pi^e)$. Thus,

$$F(\pi^c) = (1-\gamma)F(\pi^d) + \gamma F(\pi^e)$$
$$F(\pi^c) = F(\pi^d) - \gamma F(\pi^d) + \gamma F(\pi^e)$$
$$\gamma(F(\pi^d) - F(\pi^e)) = F(\pi^d) - F(\pi^c)$$
$$\gamma = \frac{F(\pi^d) - F(\pi^c)}{F(\pi^d) - F(\pi^e)} \tag{4.12}$$

By the same logic, if $\pi^c = (1-\gamma)\pi^d + \gamma\pi^e$:

$$\pi^c = (1-\gamma)\pi^d + \gamma\pi^e$$
$$\gamma = \frac{\pi^d - \pi^c}{\pi^d - \pi^e} = \delta_{st}^{min} \tag{4.13}$$

From Eq. 12-13, it then follows:

$$\delta_{rpe}^{min} = \frac{\pi^d + F(\pi^d) - \pi^c - F(\pi^c)}{\pi^d + F(\pi^d) - \pi^e - F(\pi^e)} = \frac{\gamma(\pi^d - \pi^e) + \gamma(F(\pi^d) - F(\pi^e))}{\pi^d + F(\pi^d) - \pi^e - F(\pi^e)} = \gamma = \delta_{st}^{min}$$

Proof of Corollary 2

Suppose $(\pi^c, F(\pi^c))$ lies above the line connecting the points $(\pi^d, F(\pi^d))$ and $(\pi^e, F(\pi^e))$, and $\pi^d > \pi^c > \pi^e$. It then follows that for some $\gamma \in (0,1)$, such that $\pi^c = (1-\gamma)\pi^d + \gamma\pi^e$, the following inequality holds $F(\pi^c) > (1-\gamma)F(\pi^d) + \gamma F(\pi^e)$. Thus,

$$F(\pi^c) > (1-\gamma)F(\pi^d) + \gamma F(\pi^e)$$
$$F(\pi^c) > F(\pi^d) - \gamma F(\pi^d) + \gamma F(\pi^e)$$
$$\gamma F(\pi^d) - \gamma F(\pi^e) > F(\pi^d) - F(\pi^c)$$
$$\gamma(F(\pi^d) - F(\pi^e)) > F(\pi^d) - F(\pi^c)$$
$$\gamma > \frac{F(\pi^d) - F(\pi^c)}{F(\pi^d) - F(\pi^e)} \tag{4.14}$$

Since $\pi^c = (1-\gamma)\pi^d + \gamma\pi^e$, Eq. 4.13 still holds. Hence,

$$\frac{F(\pi^d) - F(\pi^c)}{F(\pi^d) - F(\pi^e)} < \delta_{st}^{min} \tag{4.15}$$

and the result 2 holds.

Proof of Corollary 3

Same as the proof of Corollary 2.

Proof of Proposition 3

Consider $F(\pi_i) : \mathbb{R} \to \mathbb{R}$ which is increasing and bounded from above.

Suppose the function $F(\pi_i)$ does not contain intervals where Corollary 2 is satisfied. Then for any $\pi^d > \pi^c > \pi^e$ and some $\gamma \in (0, 1)$, such that $\pi^c = (1-\gamma)\pi^d + \gamma\pi^e$, the following inequality holds $F(\pi^c) \leq (1-\gamma)F(\pi^d) + \gamma F(\pi^e)$. Consequently, this implies that $F(\pi^i)$ is convex. If the function is convex and bounded, it is also constant.

Thus, if $F(\pi_i)$ is not globally constant (i.e., increasing) and bounded, it must contain intervals where Corollary 2 is satisfied.

Appendix 4.B: Examples of RPE

Tim Cook - Apple Inc. (2013), Form 8-K. Date: June 21, 2013

As a result of the adoption of a performance component and regular performance measurements, and the absence of a performance multiplier, the Committee has modified Mr. Cook's 2011 award of one million RSUs to vest as follows: 100,000 RSUs remain scheduled to vest on August 24, 2016; 100,000 RSUs remain scheduled to vest on August 24, 2021; the balance of 800,000 RSUs is separated into ten equal tranches of 80,000 RSUs each that vest over the ten-year life of the award.

The Committee considered what percentage of Mr. Cook's unvested one-year RSU tranches to place at risk under the new performance criteria. Because Mr. Cook faces only downside risk from the modification, the Committee believed that less than 50% should be placed at risk. Mr. Cook, however, expressed a strong desire to set a leadership example in the area of CEO compensation and governance and requested a larger at-risk percentage. Accordingly, the Committee is placing 50% of the RSUs at risk in each future annual performance-based tranche.

The relative TSR criteria will be applied to each 80,000 RSU tranche scheduled to vest on each anniversary of the original August 24, 2011 grant date, and will compare Apple's TSR to the TSR of the companies in the S&P 500 using public data derived from Standard and Poor's. If Apple's performance is within the top third of that group, the RSUs in the tranche for that year will vest in full. If its performance is in the middle third, the RSUs in the tranche for that year will be reduced by 25%, and if its performance is in the bottom third, the RSUs in that tranche will be reduced by 50%.

Sundar Pichai - Alphabet Inc. (2022), Form 8-K. Date: December 19, 2022

The Committee currently follows a triennial grant cycle for CEO equity awards. Mr. Pichai's last equity award was granted in December 2019.

As with the 2019 award, the award consists of both performance-based and time-based equity. The vesting of a significant portion of the award will depend on Alphabet's total shareholder return (relative to S&P 100 companies) ("TSR"), and this performance-based equity may not vest at all.

The Committee recognizes Mr. Pichai's strong performance as CEO. The on-target value of the award is unchanged from the 2019 award. However, relative to the 2019 award, the Committee made two design changes such that more of the award's vesting dependent on performance: **(1) increased the proportion of performance stock units ("PSUs") to 60% from 43%, and (2) increased the performance requirement for on-target PSU payout to 55th percentile from 50th percentile of**

TSR. These changes further align Mr. Pichai's compensation to long-term shareholder value creation and Alphabet's stock performance relative to the S&P 100 over the applicable performance periods.

For this triennial award, Mr. Pichai was granted two tranches of PSUs with a target value of $63,000,000 each. The target number of PSUs was calculated by dividing the target value of the total PSU grant by the average closing price of Alphabet's Class C capital stock during the month of November 2022 (the "Average Closing Price"). The PSUs will vest, if at all, based on the TSR performance over a 2023-2024 performance period for the first tranche and over a 2023-2025 performance period for the second tranche, subject to continued employment on each applicable vesting date. Depending upon Alphabet's TSR performance, the number of PSUs that vest in a tranche will range from 0%-200% of target.

Appendix 4.C: RPE Usage and Peer Group Type

Table 4.C.1: RPE Usage Statistics (2006-2017)

Year	N	RPE (%)	Select Peers (%)	Broad Index (%)	Industry Index (%)
2006	1,486	19.2	69.7	18.7	22.5
2007	1,467	20.9	73.0	16.8	20.1
2008	1,436	21.9	70.3	19.0	21.3
2009	1,414	23.7	72.6	18.1	18.4
2010	1,396	27.1	75.0	17.6	17.0
2011	1,382	30.2	72.7	19.2	15.8
2012	1,378	35.8	70.7	19.7	18.9
2013	1,378	40.0	66.1	21.7	22.4
2014	1,357	43.6	64.8	22.6	23.1
2015	1,321	45.9	59.4	21.6	25.1
2016	1,244	50.1	57.0	21.7	28.8
2017	1,223	53.2	48.4	21.8	36.9

Notes: The data originates from ISS Incentive Lab (IL) and is extracted from proxy statements (DEF 14A), capturing detailed information on Relative Performance Evaluation (RPE) awards granted to executive officers spanning the years 2006–2017. The table describes the prevalence of RPE usage among the largest 750 US firms (this set changes from year to year, with back and forward-filling - hence the number of the firms changing), measured by market capitalisation in each respective year. The panel also provides insights into the various peer group types employed for benchmarking during this period. Rows and columns may not add up to 100% because firms can use more than one RPE award with different characteristics. The table is lifted from Bizjak et al. (2022) - Table I, panel A.

Appendix 4.D: Possible Extension

There are several restrictive assumptions that can be expected to be met with scepticism. The model considers only the strategic aspect of managers' performances. Thus, managerial contracts are assumed to be exogenous, profits and performances are perfectly observable, and the managers' efforts play no role. Firm owners have no incentives to introduce RPE measures other than to induce collusive behaviour. These limitations can be addressed by extending the model to include managerial effort in a way similar to Salas Fumas (1992) or Asseburg and Hofmann (2008). Both papers assume the firm's gross profits to be separable in the manager's efforts and strategic actions.

$$\Pi_i = \pi_i(a_i, a_{-i}) + e_i + \epsilon_i + \eta$$

where $\pi_i(a_i, a_{-i})$ is the profit function of the firm that depends on strategic actions (a_i, a_{-i}), e_i is the manager's costly effort[21], ϵ_i is a firm-specific shock for each company in N and η is an index-wide shock (i.e. affecting all N companies in the economy). In this setting, if the manager is risk-averse, both $\gamma > 0$ and the RPE component can be justified from the efficiency perspective.

Introducing noise on the company level makes the model less tractable. Proposition 1 is expected to hold, as the collusion would still increase firms' gross profits. The precise conditions for Proposition 2 would depend on the coefficients of risk aversion of the manager and the change of probability of outperforming the median firm in the index N. It is also reasonable to assume that the effort levels of the CEOs may decrease since they can achieve a higher probability of winning via collusion, which is costless from their perspective.

[21] Both Salas Fumas (1992) and Asseburg and Hofmann (2008) propose that manager can, for example, decrease fixed costs in period t, depending on his effort.

Chapter 5

Overall Discussion and Conclusion

5.1 Summary

The present thesis investigates the effects of Relative Performance Evaluation awards in strategic environments. More specifically, the thesis poses two primary research questions:

1. *What are the causal effects of Relative Performance Evaluation (RPE) bonuses on individual strategies of the managers?*
2. *What are the causal effects of the presence of Relative Performance Evaluation (RPE) bonuses on market outcomes?*

Chapter 2 focuses primarily on answering the first question. The reported experiment compares individual response functions under the standard compensation scheme (absolute performance evaluation - APE) and the RPE-based compensation scheme. The findings indicate that response functions under RPE-based contracts contain more aggressive actions. In the context of the experimental framework (quantity setting duopoly), aggressive actions are characterised by increased quantity choices. Additionally, the experimental results demonstrate that RPE awards increase the likelihood of over-aggressive behaviour. When participants were incentivised by the RPE-based contract, they were more likely to sacrifice not only their company's profits but also their compensation to harm their direct competitors. In other words, the findings demonstrate that RPE awards encourage more aggressive behaviour than the theory predicts.

Chapter 2 employs a static environment to elicit individual response functions under both contracts. In contrast, Chapter 3 investigates dynamic settings and compares duopoly market outcomes under different compensation scenarios: where no, one, or both managers receive RPE-based contracts. It distinguishes between environments that only allow tacit collusion and those where managers can form explicit agreements (i.e., engage in cartel-like behaviour). Experimental data reveals that markets become more competitive if participants' compensation includes an RPE-based bonus. This outcome can be seen as a direct consequence of the changes in individual strategies described in Chapter 2. However, the possibility of making explicit agreements subdues this pro-competitive effect of the RPE awards. The experimental results also suggest that these agreements are less stable under RPE-based compensation.

Chapters 2 and 3 assume that the RPE awards include firms in the same industry and provide conclusive evidence that RPE awards of this kind intensify competition in the market. Chapter 4 adopts a different approach and explores RPE awards that either exclude direct product market peers or use a broad market index as their benchmark. The presented theoretical model reveals that RPE-based compensation can be pro-collusive when direct competitors are absent in the benchmark peer group. RPE bonuses commonly employed in practice exhibit the described qualities that encourage collusive tendencies. Recognising the limitations of using observational-level data to establish a causal relationship between these specific types of RPE awards and collusion, the chapter proposes an experimental test of its theoretical predictions. Broadly, Chapter 4 highlights that the RPE awards' structure and the peer groups' composition are crucial in determining market dynamics and calls for a more critical evaluation of the current practices in executive compensation.

5.2 Implications

Combined, the chapters in this thesis explore the intricacies of using RPE awards in both static and dynamic strategic environments. The broader implications of the reported findings and theoretical predictions can be evaluated from two distinct perspectives.

From the perspective of profit-maximising owners, using RPE awards with direct competitors is detrimental to their firm's performance. As evidenced by results in Chapter 3, the firms' profits are strictly lower if the managers' contract includes an RPE component. These consequences are unintended if the rationale behind using such contracts is based on the informativeness principle (Holmstrom, 1979). However, even under the framework of strategic delegation (Vickers, 1985; Salas Fumas, 1992), the use of RPEs is not justified from the profit-maximising standpoint. According to the strategic delegation framework, if one of the managers is compensated by the RPE contract while the other is compensated by the standard absolute performance contract, the RPE-using firm would achieve a more dominant market position. Findings in Chapter 3 show that the opposite is true, as the rival manager often retaliates, thereby nullifying any advantage of committing to a more aggressive strategy. Furthermore, as demonstrated in Chapter 2, RPE awards result in more *over*-aggressive actions compared to a standard compensation scheme, suggesting that this approach in executive compensation can amplify existing spiteful behaviours. The latter conclusion supports Behavioural Agency Theory (Pepper et al., 2019), as it implies that external incentives interact with internal preferences throughout managerial decision-making processes. Therefore, incentive designers must consider the risk of inciting "competitive irrationality" (Graf et al., 2012) by incorporating direct competitors into the RPE reference groups. This concern can be alleviated by excluding competitors from the RPE benchmarks or using a broad market index. As noted in the theoretical analysis in Chapter 4, constructing peer groups in this way may have an additional benefit for the owners, depending on the structure of the award. If the RPE award has concave intervals or is capped, the managers are encouraged to collude, increasing the firm's profits. Incentive designers can take further steps to promote collusive behaviour. For example, suppose the bonus payout structure is only concave in its upper half. In that case, it is possible to choose under-performing peers so that the focal firm's manager is closer to the concave interval.

From the perspective of broader societal interests, the conclusions about RPE awards are reversed. Chapters 2 and 3 of this thesis provide empirical evidence that RPE awards that include direct market peers increase competition levels and consumer surplus in oligopolistic markets. Thus, promoting the use of such RPE awards is a viable policy for improving allocative efficiency. For example, Walker (2019) suggests that the welfare-enhancing effects of RPEs can counteract the negative effects of intra-industry common ownership[1] - the issue highlighted in several recent works (Benndorf and Odenkirchen, 2021; Hariskos et al., 2022). Additionally, while Bloomfield et al. (2023) report that cartels are more likely to use RPE awards that include competitors, the results in Chapter 3 hint that doing so makes cartels less stable. Therefore, encouraging the use of RPE awards may have the added benefit from the view of antitrust authorities. However, as highlighted in Chapter 4, a close examination of the RPE award's structure and reference group composition is required for an informed policy decision. More specifically, excluding product market peers from the relative performance analysis and using tournament-like structures can induce collusive tendencies. Thus, the competition authorities should not only advocate for the use of RPE awards in general but also encourage using product market peers as performance benchmarks. For example, a recent study by Lobo et al. (2018) implies that one way of achieving this could be increasing accounting comparability within different industries.

5.3 Limitations and Suggestions for Further Research

Each chapter in this thesis is complemented by a discussion of its specific limitations, providing detailed insights into the scope and boundaries of individual analyses. Building upon this foundation, this section expands the perspective to offer a holistic overview of the broader constraints and challenges that span the entire research framework. This comprehensive approach allows for an in-depth understanding of the overarching limitations and sets the stage for identifying future research opportunities.

The primary methodology of this thesis is experimental testing, which, while robust (Askarov et al., 2023), carries inherent limitations due to the need to define specific experimental environments. In Chapters 2-3 and the proposed experiment in Chapter 4, a symmetric quantity-setting duopoly forms the basis for theoretical analyses. Simplifying the experimental setting, as justified by Normann and Ruffle (2011), ensures strong internal validity but may constrain the broader applicability of the findings. As Huck et al. (2004b) and Fischer and Normann (2019) note, different market specifics like price competition, a larger number of firms, or asymmetric cost structures might yield different results. Therefore, a valuable direction for future research would be to investigate these diverse market compositions.

A common issue in social science experiments, including those presented in this thesis, concerns potential critiques regarding sample selection. Specifically, Chapter 2 of

[1] Common ownership occurs "when one or more owners of a company also own shares of one or more other companies in the same industry" (O'Brien, 2017).

this thesis employs a general population sample, while Chapter 3 utilises a student population. The critical question that emerges from this approach is whether the findings drawn from these populations can be generalised to the target population, in this case, executive managers. In the context of market experiments, Frechette (2011) states that "overall much of the big picture seems the same whether one looks at professionals or students in laboratory experiments testing economic models". This perspective suggests that the core conclusions of this thesis are both relevant and transferable. However, there is also considerable evidence that managers often possess different attitudes and decision-making patterns due to their unique experiences, responsibilities and potential self-selection (Trottier and Gordon, 2016; Urbig et al., 2019; Buser et al., 2021). Thus, a promising yet more logistically challenging and costly avenue for future research would be conducting field experiments with actual managers. This suggestion is exceedingly fitting for the framework in Chapter 2, which partially explores the behavioural aspect of the RPE awards. My co-author and I argue that our results likely underestimate the potential of RPE bonuses to encourage over-aggressive behaviour. Conducting experiments with managers could yield insights that are more directly useful for contract designers, enhancing the practicality of our findings.

Chapters 2 and 3 of this thesis operate under simplifying assumptions, considering linear payout structures and peer groups composed of just one competitor. While these assumptions facilitate a clearer analysis, they may not fully capture the complexity of real-world scenarios. As outlined in the introduction, such payout structures, similar to accounting-based bonuses, do exist in practice. However, as the theoretical part of Chapter 4 highlights, there are a variety of RPE awards payout structures, each potentially leading to different outcomes, e.g., a rank-based tournament setting. The experimental design proposed in Chapter 4 is tailored to include commonly used forms of RPE awards, offering a framework that addresses this limitation. Although it initially focuses on RPE awards that exclude competitors, this versatile design can be adapted to incorporate different payout structures and peer groups, allowing future research to investigate how these variations might influence outcomes. This flexibility paves the way for a deeper exploration of the nuanced effects of RPE awards.

Lastly, the allocation of contracts in the reported experiments is deliberately exogenous, a decision made to establish a clear causal relationship between RPE awards and their effects on managerial strategies and market dynamics. However, this approach overlooks the potential influence of managers' preferences on their contract choices. It is conceivable, as Bebchuk et al. (2002) suggest, that managers might influence or self-select into remuneration structures that align with their unobservable objective functions, e.g., aggressive tendencies. If true, this scenario could amplify the observed effects of RPEs on company profits and overall welfare. While Miller and Pazgal (2002) propose a theoretical model considering managers' preferences, the aspect of self-selection in relation to compensation structures remains unexplored. Investigating this self-selection mechanism could yield further insights into how personal managerial attributes interact with compensation structures. This research direction can further complement the findings of this thesis and be particularly relevant for practitioners.

5.4 Closing Words

This thesis investigates the effects of Relative Performance Evaluation (RPE) bonuses in executive compensation schemes, employing an experimental approach that is both well-established (Normann and Ricciuti, 2009; Normann and Ruffle, 2011; Potters and Suetens, 2013) in industrial economics and particularly well-suited for this research objective.

I hope the insights and methodologies presented here will serve as a foundation for further discussions and research, broadening our understanding of the complex interplay between executive compensation mechanisms and market dynamics.

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