

# Essays in Experimental Economics



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TO MY FAMILY  
(Shlomo, Nina, Sharon and Anat)

## Preface

The work presented in this thesis is a result of collaboration mainly with my thesis supervisor Prof. Dr. Till Requate, but also with other colleagues within the University of Kiel and outside it. Citation to this thesis should be as presented below:

- Chapter 1 presents a joint study with Till Requate. Citation to this study should take the form:  
Waichman, I., and Requate, T. (2009), “On the role of personality traits in oligopoly experiments”, University of Kiel, Mimeo
- Chapter 2 presents a joint study with Till Requate and Ch'ng Kean Siang. Citation to this study should take the form:  
Waichman, I., Requate, T., and Kean Siang C. (2008), “Managers and students playing Cournot - experimental evidence from Malaysia”, Economic Working Paper: 2008-19, University of Kiel
- Chapter 3 presents a joint study with Eva Camacho-Cuena and Till Requate. Citation to this study should take the form:  
Camacho-Cuena E., Requate T., and Waichman, I. (2009), “Environmental policy incentives to adopt an advanced abatement technology with asymmetric firms: An experimental approach”, University of Kiel, Mimeo
- Citation to chapter 4 should take the form:  
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- Appendix A presents a joint study with Helmut Herwartz. Citation to this study should take the form:  
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Finally, I would like to thank my parents: Shlomo and Nina Waichman whom I will never be able to repay for their love, support, and encouragement. This work is dedicated with my love to them (and to my younger sisters, Sharon and Anat).

## Executive Summary

This thesis consists of studies in the field of experimental economics. The first two chapters of the thesis deal with the issue of subject selection in Cournot Oligopoly experiments. In particular, chapter 1 presents a study which was designed to test whether a predominant personality inventory (NEO-PI-R) can account for differences in behavior between subjects in a Cournot Duopoly with random matching. Chapter 2 investigates whether Malaysian managers behave differently than Malaysian students (and German students) in a Cournot Triopoly. Chapter 3 presents a study in the field of environmental economics that investigates whether the initial allocation of emission permits and the auction design affect the adoption of advanced technology in a market with many small asymmetric firms, particularly, when the regulator commits himself *ex-ante* to the level of permits. Chapter 4 provides a natural investigation of a market sharing certain features with the ultimatum bargaining game. The introduction of the Schleswig-Holstein ticket (S-H ticket) by the German train company created a market which is characterized by ‘proposers’ who offer to take ‘responders’ with their ticket for a specified price. A deadline imposed by the trains’ departure time on the bargainers transforms the situation into an ultimatum bargaining situation. Chapter 4 thoroughly describes this market, which we refer to as the Kiel market for budget travel by train. Finally, Appendix A presents a bootstrap approach to determine critical values for the dynamic quintile test as a common diagnostic tool for model based Value-at-Risk estimates.



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# Introduction

In recent years the use of experimental methods became an important tool in Economics. In contrast to happenstance data, experimental data is identified by some degree of control or internal validity<sup>1</sup>. Thus, experiments can test (the descriptive validity of) economic theories, and can improve predictions in economic situations when theory provides ambiguous results. Experiments may also trigger the development of new hypotheses and theories, and serve as ‘test beds’ for economic policies and regulations.

Experiments are conducted either in the laboratory, a controlled environment allowing an isolation of the effect of the investigated variable, or, in the field. This last example is a natural environment which allows, in general, less control over the variables being investigated. [Harrison & List \(2004\)](#) developed the conventional taxonomy in distinguishing between laboratory and field experiments. They distinguish between a conventional lab experiment, an artefactual field experiment, a framed field experiment, and a natural field experiment. A conventional lab experiment is a controlled experiment conducted with student subjects and abstract framing. An artefactual field experiment is a conventional lab experiment conducted with a non-standard subject pool (e.g. market professionals, etc.). A framed field experiment is an artefactual field experiment conducted with a particular field context. A natural field experiment is an experiment conducted in an environment where the subjects naturally undertake the task, without awareness that they are participants in an experiment. Since artefactual and framed field experiments are basically lab experiments, they enjoy a high degree of internal validity, but may suffer from a low degree of external

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<sup>1</sup>Following [Meyer \(1995\)](#), internal validity refers to whether one can draw conclusion about a change in the dependent variable as a result of a change in the explanatory variable.

validity (the extent which results from the laboratory can be generalized to the real-world). The opposite is true for natural field experiments.

This thesis presents four economic experiments conducted within a period of two years (from December 2006 to November 2008), mainly at the experimental economics laboratory of the University of Kiel. Using Harrison and Lists' taxonomy, this thesis includes two conventional laboratory experiments (chapters 1 and 3), an artefactual field experiment (chapter 2), and a natural field experiment (chapter 4). We deviate from Harrison and List's taxonomy by writing the instructions and conducting each of the experiments featured in this thesis by referring to the economic framing (rather than to the abstract framing). There are several reasons for this: First, in the first two chapters we report the results of Cournot Oligopoly experiments. In contrast to other laboratory experiments (in economics), Oligopoly experiments are conducted by referring to the economic framing rather than by referring to an abstract framing. In particular, the random-matching experiments by [Holt \(1985\)](#) and [Huck \*et al.\* \(2001\)](#), to which we refer to in chapter 1, and the experiment by [Huck \*et al.\* \(2004\)](#), whose design was followed in chapter 2, were conducted by referring to the economic framing. [Huck \*et al.\* \(2004\)](#) compared the results of Cournot Oligopoly experiments conducted with and without an abstract framing and found that “[by referring to an abstract framing] collusion may be difficult to achieve even in markets with only two participants. In general, average quantities are closer to the Cournot prediction than with an economic frame.” ([Huck \*et al.\*, 2004](#), p.444). The second reason for referring to the economic framing is the relative complexity of the experiment in chapter 3. Economic framing (context) may increase transparency regarding the experiment. This follows [Loewenstein \(1999\)](#), who points out that “a major discovery of cognitive psychology is the degree to which all forms of thinking and problem solving are context-dependent, including such seemingly straightforward tasks as language-comprehension” ([Loewenstein, 1999](#), p.F30). Moreover, Loewenstein also claims that “context-free [abstract framing] provides the same amount of context, albeit somewhat more alien, as any other environment” ([Loewenstein, 1999](#), p.F30).

The first two chapters of this thesis deal with the issue of subject selection in Cournot Oligopoly experiments. The classical quantity-setting (Cournot)



Oligopoly is a prominent example of strategic interaction among firms. Experiments on Cournot Oligopoly were among the first conducted in economics (Hoggatt, 1959; Selten & Saueremann, 1959). Since then, numerous experimental studies have been conducted in the area, providing us with better understanding of the conditions that facilitate (and impede) collusion.<sup>2</sup> However, although dealing with a firm's behavior, Cournot Oligopoly experiments were only conducted with student subjects. The question that naturally arises is thus: *Is there a substantial external validity concern when conducting Cournot Oligopoly experiments with students instead of firms (or firms' managers)?*

A first consideration regarding this question comes from Social-Psychology. Psychologists have, already long ago, suggested that behavior is a function of the individual's personality and the specific situation<sup>3</sup> (Lewin, 1936). Thus, if personality plays a *crucial* role in determining behavior, then experiments dealing with the behavior of firms should be conducted with managers as subjects (similarly, experiments dealing with governmental regulation should be conducted with government officials). In contrast, if it is the situation which mainly determines behavior, subject selection should not affect the experimental results. The problem is that we cannot observe internal causes of behavior, therefore we cannot infer whether (and how much) personality affects behavior. That leads to a huge controversy in psychology known as the personality-situation controversy.

In order to avoid the controversy, economists are following the principles of the theory of induced valuation (Smith, 1976). This theory aims at inducing a general conclusion about the economic situation regardless of the subject population. The idea is to eliminate the innate characteristics of the subjects by paying them a monetary reward. Ideally, the payment follows the principles of salience (the reward depends on the subject's action), and dominance (the subject's utility from the reward should dominate any other consideration when acting in the experiment). Therefore, most economic experiments are conducted with students, under the assumption that the results were influenced by the economic situation (including the reward structure), and not by the heterogeneous characteristics of

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<sup>2</sup>See Huck *et al.* (2004) for a survey.

<sup>3</sup>We refer to the *personality* as internal causes of behavior and to the *situation* as external causes of behavior.

the subjects. Moreover, the principles of saliency and dominance make it harder to conduct experiments with a non-student population since it is quite costly to pay market professionals, and managers especially (according to their opportunity costs).

Inspecting the literature does not solve the question. The literature in experimental economics provides contradicting evidence on the effect of subject pool selection (in particular, students vs. managers) on subject's performance. On the one hand, there are studies that do not find substantial differences in performance between students and managers. For instance, [Cooper \*et al.\* \(1999\)](#) found that without a *familiar context* managers of state enterprises in China did not perform better than students in a 'ratchet effect game'. [Montmarquette \*et al.\* \(2004\)](#) showed that managers in a large French-German pharmaceutical firm do not perform differently than students in a 'real effort game'.<sup>4</sup> [Ball & Cech \(1996\)](#) found only little evidence of subject pool effect between students and market professionals in their review. On the other hand, some studies find that managers are more cooperative than students. For instance, [Fehr & List \(2004\)](#) found that CEOs from the coffee mill sector in Costa Rica are considerably more trusting and exhibit more trustworthiness than students in a 'trust game'. [Alpizar \*et al.\* \(2004\)](#), using the same subject population, found that Costa Rican managers cooperate (abate) significantly more than Costa Rican students in two 'pollution compliance games'. Similarly, [Cooper \(2006\)](#) in a study of a 'corporate turnaround game', found that managers overcome a history of coordination failure significantly faster than undergraduate subjects.

A two-fold approach is used to investigate the issue of subject pool selection in Cournot Oligopoly experiments. In chapter 1, we investigate whether a predominant personality inventory (the NEO personality inventory revised) can account for differences in behavior between subjects in a Cournot Duopoly experiment. In chapter 2, we study whether Malaysian managers behave differently than Malaysian students (and German students) in a Cournot Triopoly experiment.

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<sup>4</sup>Nevertheless, they find that students and managers differ in their strategies, students are more cost-driven and managers are more objective-driven.

In particular, chapter 1 presents an experimental investigation of whether and which personality traits affect subjects' behavior in a random-matching Cournot Duopoly with complete information. We are particularly interested in the influence of personality under a random matching scheme, since a strategic relationship with one partner cannot be established. Besides testing the effect of personality on performance, we challenge the results of previous random-matching Cournot Duopoly experiments, by increasing substantially the gains from cooperation (inevitably, this also increases the vulnerability of a firm to its rival's defection). The Appendix of this chapter and the general Appendix (Appendix A) provide an additional contribution in the field of Econometrics. The experiment required subjects, playing the role of firms, to choose (make an output decision) integer quantities within a bounded range. Thus, when testing for the influence of personality variables on the quantities chosen by the subjects, the dependent variable is not a continuous variable but rather a discrete one. An econometric issue is whether hypothesis tests (in particular, a single-hypothesis test (t-test), and a joint-hypotheses test (F-test)) yield exact results in the case of a discrete dependent variable. Appendix A presents a bootstrap application, similar to [Herwartz & Xu \(2009\)](#), that could be applied in case the tests are shown to be inexact. Nevertheless, using our data we find that hypothesis tests yield exact results.

Chapter 2 presents a standard (fixed-matching) Cournot Triopoly experiment with different subject pools: German students, Malaysian students and Malaysian managers. This study replicates the design of [Huck \*et al.\* \(2004\)](#) in order to investigate one aspect of external validity, which is whether the use of student subjects instead of managers is justified.

The next study, included in chapter 3 of the thesis is in the field of environmental economics. This study deals with the issue of optimal policy incentives to adopt advanced technology. The motivation to this study dates back to [Kneese & Schultze \(1975\)](#), which were the first to emphasize that, among all available criteria to judge the efficiency of the different pollution control policies, one of the most important is the extent to which a given policy encourages firms to develop or adopt advanced technologies. Regarding the last statement, there is a distinction in the literature between models of technology innovation, i.e. development

of new technology, and models of technology diffusion, i.e. adoption of new but yet existing technology (see the reviews by [Jaffe \*et al.\*, 2002](#) and [Requate, 2005](#)). Our study centers on the last case. [Downing & White \(1986\)](#), [Malueg \(1989\)](#) and [Milliman & Prince \(1989\)](#) made the first attempts to rank environmental policy instruments taking the adoption of advanced technologies as an efficiency criterion. These studies, however, focus on the effect of the adoption of new technology on the whole industry, and not on the incentives of a single firm to adopt the new technology, using the aggregate cost saving as investment criteria. Consequently, [Kennedy & Laplante \(2000\)](#), and [Requate & Unhold \(2001, 2003\)](#) (for the case of adoption of new technology), and [Montero \(2002a,b\)](#) and [Fischer \*et al.\* \(2003\)](#) (for the case of technology innovation) suggested that equilibrium considerations should be taken into account when studying the incentives to adopt (or develop) new technology, that is, the number of firms that adopt (develop) the new technology in equilibrium should be endogenously determined. Moreover, Requate and Unold show that for both, a completely symmetric model (see [Requate & Unhold, 2003](#)), and an asymmetric model (see [Requate & Unhold, 2001](#)), the socially optimal allocation can theoretically be implemented, by issuing the *ex-ante* socially optimal number of emission permits.

Chapter 3 presents an experimental investigation in the laboratory of the case described in [Requate & Unhold \(2001\)](#) where firms are small and asymmetric and when the regulator takes into account the potential technological change when deciding on the environmental policy to be applied. This study is particularly interesting because it is among the few experimental studies which consider dynamic efficiency when evaluating environmental policy. We consider a market with 18 firms of five types (the types are characterized by their abatement cost functions). All firms could adopt one advanced technology for a fixed payment. We then investigate the firms' behavior, depending on whether or not they have received an initial allocation of permits (auctioning vs. grandfathering), and depending on the specific auction design. Typically, under a system of grandfathering, firms can bilaterally trade permits. To mimic this it is natural to implement a single unit double (oral) auction. Under the so called auctioning-system of permits, several designs are possible. We chose an ascending clock auction because of its simplicity. By doing so, two features are different between the treatments:

The allocation mechanism and the auction design. Therefore, we conducted an additional treatment where permits are initially allocated for free, but the price is determined by an ascending clock auction. Thus, only one feature is different between this new treatment and each of the other two treatments. Furthermore, we conducted two types of treatments, the single-period and the multi-period treatments. The single-period treatments consist of two phases: In the first phase subjects decide whether or not to invest and in the second phase they participate in an auction. This auction will determine their number of permits, and, thus, their emission level (=abatement level). In the real world, however, investment does not always happen simultaneously. Firms might first wait and observe the other firms' behavior, and only then decide whether to invest in the new technology. In this sense, we conducted further series of treatments where the relevant time horizon is four periods. As in the single-period treatments each period consists of two phases: In the first phase subjects decide whether or not to invest (only if they did not invest in the previous periods), and in the second phase they participate in an auction. We refer to these treatments as the multi-period treatments. We are interested in possible deviations from (i) the optimal investment in advanced abatement technology, (ii) the efficient allocations of permits (reflected in the total abatement costs given the investment decision), and (iii) the optimal total social welfare in the economy. In addition, we employ the low-payoff menu of paired lottery (Holt & Laury, 2002) to learn whether subjects' attitudes towards risk affect their performance in the laboratory.

So far, the studies included in this thesis are laboratory experiments in the field of industrial organization. In these studies subjects play the role of firms operating in markets which are defined by the experimenters. The last chapter of this thesis, chapter 4, presents a natural field experiment which was influenced by the literature on bargaining experiments<sup>5</sup> and in particular by the ultimatum bargaining game (UG).<sup>6</sup> This experiment was conducted in the main train station of Kiel, Germany.

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<sup>5</sup>Roth (1995) provides an excellent review on bargaining experiments.

<sup>6</sup>The ultimatum bargaining game is a sequential game where Player A divides a pie of size  $x$  between himself and another Player B. Player B, then, decides whether to accept and receive the division made by Player A, or to reject the division. If Player B rejects, both players receive zero.

Since it was introduced by Güth *et al.* (1982), the UG serves as a prominent and consistent example of a situation where the observed behavior deviates significantly from the game theoretical prediction. There is, however, criticism whether UG indeed describes a real world phenomenon (see Grace & Kemp, 2005, p.824). This motivates the search for real-world situations having an UG structure. The introduction of the Schleswig-Holstein ticket (S-H ticket), by the German train company (Deutsche Bahn) created a market for budget travel by train. The S-H ticket allows up to five people to travel together for a fixed price in regional trains within two federal states in northern Germany for nearly an entire day. Due to the feature that only a single passenger who rides with the S-H ticket can continue using it after separating from the others, it is worthwhile for some passengers (for instance, passengers who need to use the ticket later) to buy the S-H ticket and offer to take others with their ticket for a specified price. Thus, this market is characterized, not by spontaneous gatherings of passengers who want to share the cost of traveling, as one could expect, but rather by ‘proposers’ who offer to take ‘responders’ with their ticket. A deadline imposed by the trains’ departure time on the bargainers transforms the situation into an ultimatum situation. Thus, by investigating this market we could learn about the behavior of proposers and responders in a situation restricted by a deadline. Chapter 4 thoroughly describes this market, which we refer to as the Kiel market for budget travel by train. In particular, we start by characterizing and describing the empirical features of the market. In this part, we center our analysis on the proposers’ behavior (especially we analyze whether proposers offer to take responders for a price that maximizes their revenue). We continue by describing the ‘ride-share community’, a popular market for budget travel by car in Germany and compare it to the Kiel market for cheap train ride. Finally, we investigate the responders’ behavior in the Kiel market for budget travel by train by entering the market as proposers.

# Chapter 1

## On The Role of Personality Traits in Oligopoly Experiments

### 1.1 Introduction

A major controversy in psychology is whether the behavior of (economic) agents is mainly determined by the agent's personality or by the specific situation in which he is operating.<sup>1</sup> Economists have largely ignored this debate since they believe that the situation is the main determinant of behavior. In fact, the theory of induced value (Smith, 1976) aims at reducing the role of subjective values (or innate characteristics) associated with market decisions.

Two sources of evidence motivate the examination of personality characteristics when modeling strategic interactions among firms (or firms' managers): First, studies in *organizational psychology* provide evidence for a correlation between certain personality traits and managerial success (e.g. Harrell & Alpert, 1989; Judge *et al.*, 1999). Second, following Shackleton & Newell (1997), 64% of the big companies in the UK and about 33% of those in the US use personality measures in the selection of managers. This evidence suggests that personality traits may be responsible for managerial success.

Although the role of certain personality traits in explaining behavior has already been tested in a prisoners' dilemma game (PD), a game with only two pure

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<sup>1</sup>Mechelen & Raad (1999) provide a short review on this controversy.

strategies, and in a few other economic experiments, we believe that testing the role of personality traits is in particular worth to be pursued in market competition games with many different possible actions and strategies. Especially the seminal quantity-setting Oligopoly game (Cournot competition) offers a rich and differentiated test bed for investigating the relationship between personality traits and behavior in a potentially competitive situation. Such a test is particularly interesting under a random matching treatment since a long-term relationship with one partner cannot be established.

In this paper we report results from a two-stage experiment aiming to test whether personality, as reflected by the Five Factor Model (FFM), affects behavior in a Cournot Duopoly. In the first stage, the subjects had to fill in the NEO Personality Inventory Revised (NEO-PI-R), and in the second step, about one month later, a subsample of these subjects participated in a Cournot Duopoly experiment with random matching. Our design draws largely on the ‘easy’ treatment by [Bosch-Doménech & Vriend \(2003\)](#). We chose, however, a larger ratio between collusive and Cournot profits than was used in the previous random matching experiments ([Huck \*et al.\*, 2001](#) and [Holt, 1986](#)).<sup>2</sup>

The FFM was originated from the lexical approach, following the idea that the most important personality traits are encoded within the natural language.<sup>3</sup> The mappings of the language in search for the basic dimensions of personality (using factor-analysis to organize personality term into few general categories) have brought to a growing recognition among psychologists that personality can be described by five dimensions (see [Digman, 1990](#)). These dimensions are numbered and labeled as follows:<sup>4</sup> I. *Extraversion* (or *Surgency*) II. *Agreeableness* III. *Conscientiousness* (or *Will*) IV. *Neuroticism* (or *Emotional Stability*) V. *Intellect* (or *Openness to experience*). The NEO-PI-R ([Costa & McCrae, 1992](#)) is a predominant<sup>5</sup> self-report inventory based on factor analysis which was specifically designed to measure the FFM, as such, it provides a general description of a

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<sup>2</sup>In contrast to earlier studies using collusion/Nash-equilibrium profit ratio of 1.125 ([Huck \*et al.\*, 2001](#)) and 1.05 in ([Holt, 1986](#)), we chose this ratio to be 1.5.

<sup>3</sup>See [John \*et al.\*, 1988](#), for an excellent review on the lexical approach.

<sup>4</sup>Although there is a broad recognition about the five dimensions there is some debate about the names (and specific definitions) of these dimensions.

<sup>5</sup>According to [John & Srivastava \(1999\)](#) it is the best-validated Big Five measures in the questionnaire tradition.



## 1.2 The Effect of Personality in Economics Experiments

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normal personality of adults and adolescents. The NEO-PI-R has some very plausible features, among them its high validity<sup>6</sup>, it has been widely used in various situations (e.g. clinical settings, business and industries counseling, psychological and educational research), and in various countries and cultures.

The main finding of this paper is that in the first period of the experiment collusive behavior is significantly correlated with high *conscientiousness* and female sex. There is, however, even in the first period no significant correlation between performance and any of the other four personality domains, especially not with those traits we would expect to find a correlation, such as *agreeableness*. In the final periods, when subjects have gained experience, we find that, in line with economic theory, their performance is largely independent of personality traits.

Finally we establish that the relatively high ratio between collusive and competitive profits, as was chosen in our experiment, does not induce more collusion than in previous experiments. Rather, the Nash equilibrium is still the best predictor, at least in this random-matching Cournot Duopoly game.

The paper is organized as follows. In section 1.2 we briefly review the literature investigating the role of personality traits in other economic experiments. In section 1.3 we portray the experimental design. In section 1.4 we present our results, and in section 1.5 we draw our conclusions.

## 1.2 The Effect of Personality in Economics Experiments

### 1.2.1 Prisoner's Dilemma experiments

The role of personality traits in PD experiments has been investigated much before experimental economics started to boom. An extended survey of this literature is given by [Rubin & Brown \(1975, p.174-196\)](#). [Harnett et al. \(1968\)](#) find that *risk-taking propensity* (defined as a general willingness to take risks in

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<sup>6</sup>Regarding the German version: Internal consistency coefficients (Cronbach's alpha) for the domain scales range from .87 to .92. Stability coefficients (test-retest reliability) for the domain scales ranging from .91 to .84 have been found in one-month and six-month longitudinal studies.

## 1.2 The Effect of Personality in Economics Experiments

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social situations), is negatively correlated with cooperative behavior, while [Pilisuk et al. \(1965\)](#) show that *tolerance of ambiguity* and *opened-mindedness* (defined as the tendency of individuals to prefer chance to regularity, ambiguity to clarity, etc.) are positively correlated with cooperation in PD-experiments. Moreover, according to [Boone et al. \(1999\)](#), *sensation seeking* (defined as an individual's motivation to experience) is also positively correlated with cooperation.

[Lindskold \(1971\)](#); [Tedeschi et al. \(1969a\)](#); [Williams et al. \(1969\)](#), and [Faucheux & Moscovici \(1968\)](#) find that low *self-concept* and high *anxiety* are positively correlated with competitive behavior.<sup>7</sup> *Self-concept* describes the set of beliefs that a person has about how he looks in his own eyes and in the eyes of others. A person with low *self-concept* has low self-esteem and high anxiety. Subjects' *predisposition to trust* others is positively correlated with cooperative behavior ([Schlenker et al., 1973](#); [Tedeschi et al., 1969b](#); [Wrightsman, 1966](#)). Factor G in Cattell and Eber's 16PF self-report inventory which reflects *morality, charity* and *dutifulness*, is positively correlated with cooperation ([Gillis & Woods, 1971](#)). *Machiavellianism* defined by [Christie & Geis \(1970\)](#) as the willingness to use opportunistic behavior in interpersonal relationship, is negatively correlated with cooperation ([Uejio & Wrightsman, 1967](#); [Wahlin, 1967](#)).

[Rotter \(1966\)](#) defines the so called *locus of control* measuring the subjective perception whether some outcome is the result of a person's self-effort. Within this concept there is a distinction between *internals* and *externals*: *Internals* believe that the outcome of a situation is determined by their own actions, while *externals* believe that it is determined mainly by external forces such as 'luck' and 'fate'. [Bobbitt \(1967\)](#) finds that *internals* are more maximizers than *externals*, and that they are less sensitive to variations in the other's behavior, while [Boone et al. \(1999\)](#) find that *internals* are more cooperative than *externals*. The latter result is related to our findings since Rotter's locus of control is correlated with *consciousness*, the only trait that significantly 'explains' performance in the first period of our quantity setting game. [Boone et al. \(1999\)](#) also find that *high self-monitoring* is positively correlated with cooperation.<sup>8</sup>

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<sup>7</sup>[Rubin & Brown \(1975, p.178\)](#) report that one study finds negative correlation between high *self-concept* and cooperative behavior.

<sup>8</sup>*Self-monitoring* is a measure of how much an individual's behavior is influenced by his surroundings (a *high self-monitoring* individual observes and controls his or her behavior while

### 1.2.2 Other economic experiments

The effect of personality traits on behavior was also tested in other economic experiments. In a variant of the bilateral monopoly game, [Harnett \*et al.\* \(1968\)](#) find that *risk-taking propensity* is correlated with competitive behavior. For the same game [Hughes \*et al.\* \(1973\)](#) find that *internals* (w.r.t. Rotter's locus of control) cooperate more than *externals*. Within a two-person one-shot constituent game (a game in which the first participant choose whether to trust or to distrust the second participant, and the second participant choose whether to reciprocate or defect), [Gunnthorsdottir \*et al.\* \(2002\)](#) find *Machiavellianism* to be negatively correlated with cooperative behavior. [Perugini \*et al.\* \(2008, forthcoming\)](#) report that *agreeableness* and *honesty* (domains in the Big Six measure by [Lee & Ashton, 2005](#)) are correlated with positive donation in a public good experiment. Similar to our findings this effect of personality vanishes with experience (in a second period of the experiment) and is larger for males than for females. [Ben-Ner \*et al.\* \(2004\)](#) find that high *agreeableness* and low *extraversion* are positively correlated with positive donation in a dictator game. [Kurzban & Houser \(2001\)](#) find that high *self-esteem* (and female gender) is positively correlated with being a free-rider in a circular public goods game. [Fahr & Irlenbusch \(2008\)](#) report that low *anxiety* is positively correlated with trustful behavior, in a trust game. [Brändstatter & Königstein \(2001\)](#) find that high score on *independence* and *tough-mindedness*, demand more than others when they are assigned the role of proposers in an ultimatum game. They also find that 'reciprocity oriented' subjects (either *emotionally stable* and *introverted*, or *emotionally unstable* and *extroverted*) reject proposals more than others. Finally, [Büchner \*et al.\* \(2007\)](#) find that the interpersonal interactivity index, which is a measure of personality characteristics related to pro-social behavior, does not predict behavior in a solidarity game.

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a *low self-monitoring* individual behaves according to his desires).

## 1.3 Experimental Design and Procedure

We set up a symmetric Cournot Duopoly experiment with a homogeneous product and random matching lasting over 20 periods. Communication between the firms (subjects) is not allowed; the feedback after each period contains information about the firm and the other firm’s performance. The firms are acting in a market with the following demand function:

$$P(Q) = \max \{480 - 4Q, 0\}, \quad (1.1)$$

where  $Q = q_1 + q_2$ . Additionally, each seller bears a fixed cost of 4800. Subjects could select integer quantities between 29 and 48. Under this setting, the individual best response (Cournot-Nash) quantity is  $q^N = 40$ , whereas the collusive quantity is given by  $q^M = 30$ , and the rivalistic quantity by  $q^R = 48$ .<sup>9</sup> We do not expect to observe only the three benchmark quantities in the experiment. Therefore, following [Fouraker & Siegel \(1963\)](#), we divide the set of possible actions into three ranges associated with the three types of strategies.<sup>10</sup> The theoretical predictions are given in Table 1.1.

|                       | Cournot-Nash     | Cooperative      | Rivalistic       |
|-----------------------|------------------|------------------|------------------|
| Individual quantities | $q_i^N = 40$     | $q_i^M = 30$     | $q_i^R = 48$     |
| (range)               | {35, ..., 44}    | {29, ..., 35}    | {44, ..., 48}    |
| Market quantities     | $Q_i^N = 80$     | $Q_i^M = 60$     | $Q_i^R = 96$     |
| (range)               | {70, ..., 88}    | {58, ..., 70}    | {88, ..., 96}    |
| Profit                | $\Pi_i^N = 1600$ | $\Pi_i^M = 2400$ | $\Pi_i^R = -192$ |

Table 1.1: Theoretical predictions

Out of the total sample of 102 undergraduate students, from different departments that completed the German version of the NEO-PI-R ([Ostendorf & Angleitner, 2004](#)), we randomly selected 36 subjects to participate in a Cournot Duopoly experiment.<sup>11</sup> The experiment was conducted at the University of Kiel,

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<sup>9</sup>In our design the *rivalistic action* was at the corner of the set of feasible actions, it is defined as  $q_i^R = q_i$  [ $\Pi_i(\mathbf{q}) - \Pi_j(\mathbf{q}); 0 \leq q_i \leq 48$ ], the other two strategies were defined as in [Fouraker & Siegel \(1963\)](#).

<sup>10</sup>A “border” quantity such as 35 is defined as being half cooperative and half Cournot.

<sup>11</sup>The average age of the subjects was 21.04 years, exactly 50% of the subjects were females.

using the z-Tree experimental software (Fischbacher, 2007). The subjects were equipped with a profit table that summarizes all possible outcomes of the game. Two (randomly-chosen) periods were taken into account for the total profit. All the entries in the profit table are expressed in *Experimental Currency Units (ECU)*. As an exchange rate we chose 400:1 (ECU/Euro).

## 1.4 Experimental Results

We start by describing aggregate outcome in the Duopoly markets, and then we examine the impact of the increased cooperation ratio on the individual firm's behavior. Finally, we test the effect of personality traits on subject's performance.

### 1.4.1 Aggregate behavior

Figure 1.1 describes the evolution of the mean market quantity over time. We see that the average quantity is in the Cournot-Nash range in all periods. Figure 1.2 presents the histograms of the pooled quantities (across 18 markets and over 20 periods). From this figure we can see that most quantities selected by the subjects are classified as either Cournot or rivalistic. More precisely, 74% of the quantities selected by the subjects were inside the Cournot range while 24% and 1% were in the rivalistic and cooperative ranges, respectively. The mean quantity is equal to 83.7 (using a t-test, we reject the null hypothesis of mean quantity equals to the Cournot-Nash quantity of 80 at the 1% s.l.).

## 1.4 Experimental Results

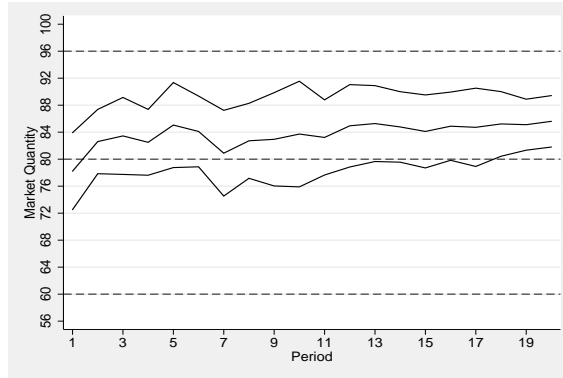


Figure 1.1: Average market quantity over time (the middle graph). The upper (lower) graph denotes the mean quantity plus (minus) one standard deviation. The dashed line denotes the benchmark quantities ( $Q^M = 60$ ,  $Q^N = 80$ ,  $Q^R = 96$ ).

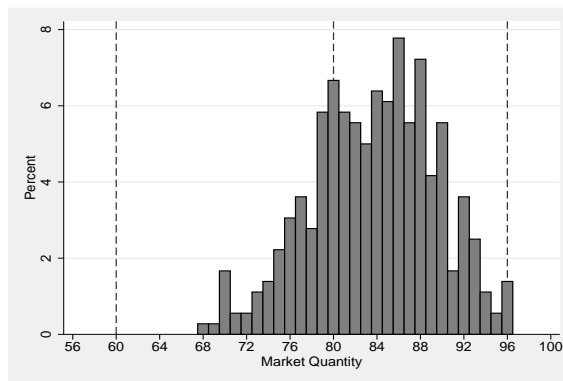


Figure 1.2: Histogram of the pooled quantities across markets and over time. The dashed lines denote the benchmark quantities ( $Q^M = 60$ ,  $Q^N = 80$ ,  $Q^R = 96$ ).

### 1.4.2 Individual behavior

As subjects gain experience during experiments, their behavior often converges. This implies that experience and thus the situation rather than the personality mainly determines behavior. To elicit the impact of personality in the absence of experience we dispensed with trial periods in order to test whether and which personality characteristics influence behavior at the beginning of the experiment and after experience has been gained.<sup>12</sup> The histograms in Figure 1.3 show the outcomes of the first and the 19th period.<sup>13</sup>

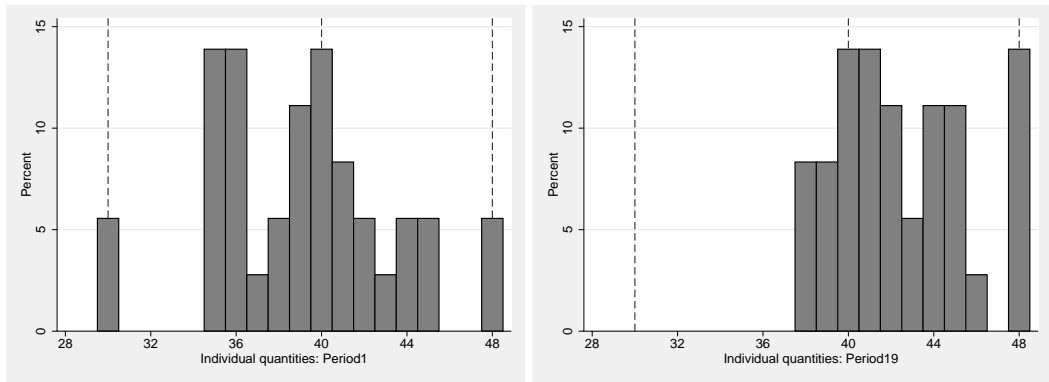


Figure 1.3: The histograms of the quantities chosen in period 1 (left) and in period 19. The dashed lines denote the three benchmark quantities ( $q^M = 30$ ,  $q^N = 40$ ,  $q^R = 48$ ).

From Figure 1.3 we see that in the first period 19% of the subjects chose a quantity inside the cooperative range of strategies, while in the 19th period only 1% of the subjects chose to cooperate (in fact, already in the second period, only 5% of the quantities are assigned to the cooperation range). Using a Wilcoxon Sign Rank test we formally reject the hypothesis that the outcome of the first period is equal to the outcome of the 19th period at the 1% s.l, finding that the first period yields a significantly higher level of cooperation than the 19th period.

Previous random-matching Duopoly experiments (Holt, 1986; Huck *et al.*, 2001) show that the Nash strategy is the best predictor in a random matching

<sup>12</sup>Nevertheless, in order to minimize the risk of subjects not understanding the environment, they had to do a simple test to establish whether they know how to use the profit table.

<sup>13</sup>Following Fouraker & Siegel (1963) and Huck *et al.* (2001), we chose the second but last period instead of the last period to eliminate end round effects.

## 1.4 Experimental Results

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Cournot Duopoly. However, in those experiments the ratio of cooperative profit to Nash profit, ranging between 1.125 in [Huck \*et al.\* \(2001\)](#) and 1.05 in [Holt \(1986\)](#), was relatively small. In our experiment we chose a ratio of 1.5. This, however, implies that the cooperator is more vulnerable. We therefore define the *vulnerability ratio* as the ratio between the Nash profit and the profit a player receives when choosing the cooperative action while the other player deviates. In our setting, this ratio is equal to  $1600/600 = 2.66$ , which is significantly larger than in previous studies (1.02-1.11 in [Holt, 1986](#) and 1.18 in [Huck \*et al.\*, 2001](#)).

Since we are not able to explicitly test for differences between experiments conducted under different settings and procedures, we pursue a qualitative approach by comparing the frequencies of the corresponding strategy ranges (*Cournot-Nash*, *cooperative*, and *rivalistic*) in the first period, in the second-last period, and the total quantities over all time periods of our study to those in [Huck \*et al.\* \(2001\)](#)<sup>14</sup> and [Holt \(1986\)](#)<sup>15</sup>. The results of the individual (firm) level classifications are shown in Table 1.2.

| Study (year), period           | % Cournot-Nash | % Cooperative | % Rivalistic |
|--------------------------------|----------------|---------------|--------------|
| Our (07), 1st                  | 73.6           | 12.5          | 13.8         |
| Our (07), 9th                  | 66.6           | 5.5           | 27.7         |
| Our (07), 19th                 | 68.0           | 0             | 31.9         |
| <b>Our (07), Total</b>         | <b>61.3</b>    | <b>4.7</b>    | <b>33.9</b>  |
| Huck et al. (01), 1st          | -              | -             | -            |
| Huck et al. (01), 9th          | 75.0           | 20.0          | 5.0          |
| <b>Huck et al. (01), Total</b> | <b>63.5</b>    | <b>24.2</b>   | <b>12.2</b>  |
| Holt (86) , 1st                | 54.1           | 33.3          | 12.5         |
| Holt (86), 9th                 | 95.8           | 4.1           | 0.0          |
| <b>Holt (86), Total</b>        | <b>85.8</b>    | <b>10.8</b>   | <b>3.3</b>   |

Table 1.2: A comparison of strategy frequencies in the first period, in the second-last period, and of the total quantities (in bold print) over all time periods of the different studies.

Using a Chi-square test we find that the observed frequencies in our study differ significantly from those observed in previous experiments ([Huck \*et al.\*, 2001](#)

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<sup>14</sup>Huck et al. (01): cooperative space: 3-7, Cournot space: 7-10, rivalistic space: 10-15.

<sup>15</sup>Holt (86): cooperative space: 4-7, Cournot space: 7-10, rivalistic space: 10-22.



and [Holt, 1986](#)).<sup>16</sup> Nonetheless, we still find that most quantities selected by the subjects in our study are in the Cournot range.

### 1.4.3 The effect of personality traits

While economic theory does not provide us with an explanation for the difference in behavior across subjects, personality traits may account for that. Thus, we test whether the domains of the NEO-PI-R (for the definitions of the five domains see Table 1.6) could explain subjects' behavior. Besides testing the effect of personality we also control for gender.

[Mason & Phillips \(1991\)](#) find that women tend to cooperate more than men in the first periods of a Cournot Duopoly experiment (though under fixed matching). Therefore we expect a similar result in our experiment.<sup>17</sup> From other previous studies we hypothesize that high *agreeableness* (which is associated with traits such as *trust*, *altruism* and *compliance*), high *extraversion* (which is associated with *excitement seeking*), high *openness* (which is associated with *open-mindedness*), high *conscientiousness* (which is associated with traits such as *competence* and *dutifulness*, thus with *internalism* according to Rotter's locus of control), and low *neuroticism* (which is associated with traits such as *anxiety* and *self-consciousness*) will be positively correlated with collusion in our Cournot experiment.

For the purpose of evaluating the overall effect of personality traits on behavior we estimate a random effect panel data model.<sup>18</sup> Beside the five personality domains and a dummy for gender, and in order to account for the interactions between the firms current decision and their experience during the experiment,

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<sup>16</sup>The frequencies observed for the total quantities are different between each pair of studies at the 1% s.l.

<sup>17</sup>Numerous PD and other bargaining experiments were investigating the role of gender on performance. However, these studies came up with ambiguous evidence (see [Rubin & Brown, 1975](#), p.169-174 for a survey of more than hundred studies).

<sup>18</sup>The model takes the following specification

$$q_{i,t} = \alpha + \beta_1 q_{j,t-1} + \beta_2 q_{j,t-2} + \mathbf{X}_i' \boldsymbol{\gamma} + \mu_i + \nu_{i,t}, \quad (1.2)$$

where  $\mathbf{X}_i$  is a matrix collecting the personality variables and a dummy for gender,  $\boldsymbol{\gamma}$  is a vector of parameters to be estimated,  $\mu_i \sim IID(0, \sigma_\mu^2)$ , and  $\nu_{i,t} \sim IID(0, \sigma_\nu^2)$

## 1.4 Experimental Results

we also include the lagged quantities of the other firm in the market ( $q_{j,t-1}$ , and  $q_{j,t-2}$ ) among the explanatory variables.

| Variable  | Coef.    | Std. Err. |
|---|----------|-----------|
| Lagged (1) rival's quantity   | 0.13***  | 0.03      |
| Lagged(2) rival's quantity  | 0.09***  | 0.03      |
| (N) Neuroticism   | 0.00     | 0.02      |
| (E) Extraversion  | -0.02    | 0.02      |
| (O) Openness  | -0.00    | 0.02      |
| (A) Agreeableness   | -0.02    | 0.02      |
| (C) Conscientiousness   | -0.01    | 0.02      |
| Gender  | -1.15    | 1.06      |
| Constant  | 39.68*** | 8.14      |
| $\sigma_u$  | 2.30     |           |
| $\sigma_e$  | 3.34     |           |
| $\rho$  | 0.32     |           |
| Observation =648; Wald $\chi^2(9) = 32.25^{***}$ ; B-P $\chi^2(1) = 27.82^{***}$<br>$R^2$ within=0.03; between=0.13; overall=0.06 |          |           |

\*, \*\*, \*\*\* denote significance at the 10%, 5%, and 1% levels, respectively

Table 1.3: Random effect estimation

Table 1.3 shows that, averaging over all periods, personality does not influence the behavior of subjects in our random-matching Duopoly. It also illustrates that after subjects have gained experience, their behavior depends also on their experience with the other firm in the market (though this effect is rather weak as indicated by the  $R^2$ ). To test the effect of personality in the absence of experience, and alternatively, after the subjects have gained enough experience, we estimate, via OLS, two models aiming at explaining the selected quantities in periods 1 and 19 using the five domains of the NEO-PI-R and gender.

## 1.4 Experimental Results

| Variable                                   | Coef.      | Std. Err.       |
|--|------------|-----------------|
| (N) Neuroticism                            | 0.00       | 0.04            |
| (E) Extraversion                           | 0.02       | 0.04            |
| (O) Openness                               | -0.05      | 0.03            |
| (A) Agreeableness                          | -0.03      | 0.04            |
| (C) Conscientiousness                      | -0.09**    | 0.04            |
| Gender                                     | -3.92**    | 1.63            |
| Constant                                   | 59.36***   | 12.15           |
| Ftest(6,29) = 2.66**                       |            |                 |
| Observation = 36                           | $R^2=0.35$ | Adj- $R^2=0.22$ |
| (a) Dep. variable: quantities in period 1  |            |                 |
| Variable                                   | Coef.      | Std. Err.       |
| (N) Neuroticism                            | -0.04      | 0.03            |
| (E) Extraversion                           | 0.01       | 0.03            |
| (O) Openness                               | 0.03       | 0.03            |
| (A) Agreeableness                          | -0.06      | 0.03            |
| (C) Conscientiousness                      | -0.00      | 0.03            |
| Gender                                     | 0.46       | 1.32            |
| Constant                                   | 46.95***   | 9.86            |
| Ftest(6,29) = 1.31                         |            |                 |
| Observation = 36                           | $R^2=0.21$ | Adj- $R^2=0.04$ |
| (b) Dep. variable: quantities in period 19 |            |                 |

Table 1.4: OLS estimations with the NEO-PI-R domains as explanatory variables: In Table 1.4(a) the dependent variable is the quantity selected in period 1. In Table 1.4(b) the dependent variable is the quantity selected in period 19. \*, \*\*, \*\*\* denote significance at the 10%, 5%, and 1% levels, respectively

From Table 1.4 we find that high *conscientiousness* and gender affect cooperation in the first period but not after the subjects have gained enough experience (period 19).<sup>19</sup> More precisely, both high *conscientiousness* and female sex are positively correlated with collusive behavior. We do not, however, observe any significant effect of the other personality domains. It is in particular surprising that *agreeableness*, associated with traits such as *trust*, *altruism*, and *compliance*, and thus apparently being related to cooperation, is not correlated with subjects'

<sup>19</sup>As in the public good experiment by [Perugini et al. \(2008, forthcoming\)](#), we find that the effect of personality vanishes already in the second period.

performance, even in the first period.

## 1.5 Discussion

A major objective of this study was to test whether it is justified to ignore personality traits of subjects playing the role of firms in laboratory experiments. In fact, not only economists but also many psychologists believe that the power of personality measures in explaining individual behavior is rather limited (see, for instance, [Mischel, 1969](#)). Performing a Cournot Duopoly experiment with random matching, we find that in the absence of experience (i.e. in the first period of a treatment), personality as measured by the NEO-PI-R and gender have some effect on the subjects' behavior. After subjects have gained experience, however, their behavior is largely independent of their personality traits.

In particular we find that, in the first period, high *conscientiousness* and female sex are correlated with collusive actions. This finding is interesting because it confirms that behavior in the laboratory may be affected by personality characteristics that are not directly related to the original research hypothesis (the *agreeableness* domain, associated with traits such as *trust*, *altruism*, and *compliance* seems *ex-ante* more directly related to cooperation).

Finally, we find that a larger *cooperation ratio* does not yield more cooperation than in previous studies. This finding may be due to the fact that the higher gain from cooperation is offset by a higher degree of vulnerability. Unfortunately, it is not possible to control for these issues separately, since a larger cooperation ratio automatically induces higher vulnerability. Overall, in line with previous studies, we find that the most frequent strategy chosen by the subjects is close to the Cournot strategy but, surprisingly enough, deviations from the Cournot-Nash prediction go more frequently into the direction of more competition rather than to collusion.

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## 1.6 Appendix to Chapter 1

### 1.6.1 Translated instructions and the profit table

#### *General Introduction*

- Welcome to our experiment. Please read the instructions carefully! From now on until the end of the experiment you are not allowed to communicate with the other participants. If you have a question, please raise your hand and we will answer your question individually.
- In this experiment you can earn a reasonable amount of money depending on your decision and also on the decisions of the others. The profit you earn in the experiment will be paid at the end of the experiment in such a way that you will not see how much the others have earned, nor will they see how much you have earned.
- You play the role of a firm selling a good in a market. Each market consists of only two firms: your firm (Firm A) and another firm (Firm B), which is identical to yours.
- At the beginning of each period we will randomly assign who will be the other firm (Firm B) in the market. However, you will never learn about the identity of the persons participating with you in the market, and they will never learn about your identity (neither during nor after the experiment).
- The experiment consists of exactly 20 periods.

#### *Experimental Procedure:*

- In each period, each firm makes one decision: the quantity of the good to be sold in the market. Only integer values between 29 and 48 can be chosen.
- Your decision and the decision of the other firm in the market (firm B) are made simultaneously.
- The profit depends on the total quantity produced by the market (which includes yours and the other firm quantity).

- You will be given a profit table showing the profit levels (or losses) that you (firm A) and the other firm's (firm B) can obtain by choosing certain quantities. The quantities of your firm (firm A) are listed across the top of the table while the quantities produced by the other firm (firm B) are listed down on the left-hand margin. The profit for your firm and the other firm are given in the body of the table by the intersection of the quantities produced. The *top* number in bold print denotes *your profit* (firm's A profit) and the bottom number denotes the profit of the other firm.
- After each period you will obtain information on your screen about the quantity chosen by you, the quantity chosen by the other firm, the profit you earned from this period, and the other firm's profit from this period.
- After each period you will also see the history of your market (your quantity, your profit, the other firm's quantity, and the other firm's profit).
- At your work place you will find an empty sheet of paper for your own use.

### ***Payment:***

- Each participant gets a 'show-up' fee of 2€ for participating in the experiment (losses will not be subtracted from this show-up fee).
- All payoffs are in ECU (Experimental Currency Unit), 400 ECU equals 1€.
- At the end of experiment, one of the participants will toss a 20-sided dice. This will be done twice (or until two different periods have been chosen). The total profit from the experiment will be the sum of the profits from the two periods selected accordingly. This will be done in front of you.
- The total profit to be earned in the experiment is the fixed amount of 6€ from filling in the questionnaire, plus the 'show-up' fee of 2€, plus the total amount earned in two randomly chosen periods.
- At the end of the experiment we will add up your profits and calculate your reward. This will be done in such a way that others will not see how much you have earned, nor will you see how much they have earned. You will get your money immediately in cash.

To be sure that you understand how to use the profit table, please check the following example:

Look at the profit table. If you choose the quantity of 31 and the other firm chooses the quantity of 36, your profit will be 1772 ECU and the other firm's profit will be 2832 ECU.

Fill in the profits in the following statement:  
When you choose the quantity of 48 and the other firm chooses the quantity of 45, your profit will be \_\_\_\_\_  
and the other firm's profit will be \_\_\_\_\_.



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| Your firm's output (A) →<br>Other firm's output (B) ↓ | 29   | 30   | 31   | 32   | 33   | 34   | 35   | 36   | 37   | 38   | 39   | 40   | 41   | 42   | 43   | 44   | 45   | 46   | 47   | 48   |
|---|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 29  | 2392 | 2520 | 2640 | 2752 | 2856 | 2952 | 3040 | 3120 | 3192 | 3256 | 3312 | 3360 | 3400 | 3432 | 3456 | 3472 | 3480 | 3480 | 3472 | 3456 |
| 30  | 2276 | 2400 | 2516 | 2624 | 2724 | 2816 | 2900 | 2976 | 3044 | 3104 | 3156 | 3200 | 3236 | 3264 | 3284 | 3296 | 3300 | 3296 | 3284 | 3264 |
| 31  | 2160 | 2280 | 2392 | 2496 | 2592 | 2680 | 2760 | 2832 | 2896 | 2952 | 3000 | 3040 | 3072 | 3096 | 3112 | 3120 | 3120 | 3112 | 3096 | 3072 |
| 32  | 2044 | 2160 | 2268 | 2368 | 2460 | 2544 | 2620 | 2688 | 2748 | 2800 | 2844 | 2880 | 2908 | 2928 | 2940 | 2944 | 2940 | 2928 | 2908 | 2880 |
| 33  | 1928 | 2040 | 2144 | 2240 | 2328 | 2408 | 2480 | 2544 | 2600 | 2648 | 2688 | 2720 | 2744 | 2760 | 2768 | 2768 | 2760 | 2744 | 2720 | 2688 |
| 34  | 1812 | 1920 | 2020 | 2112 | 2196 | 2272 | 2340 | 2400 | 2452 | 2496 | 2532 | 2560 | 2580 | 2592 | 2596 | 2592 | 2580 | 2560 | 2532 | 2496 |
| 35  | 1696 | 1800 | 1896 | 1984 | 2064 | 2136 | 2200 | 2256 | 2304 | 2344 | 2376 | 2400 | 2416 | 2424 | 2424 | 2416 | 2400 | 2376 | 2344 | 2304 |
| 36  | 1580 | 1680 | 1772 | 1856 | 1932 | 2000 | 2060 | 2112 | 2156 | 2192 | 2220 | 2240 | 2252 | 2256 | 2252 | 2240 | 2220 | 2192 | 2156 | 2112 |
| 37  | 1464 | 1560 | 1648 | 1728 | 1800 | 1864 | 1920 | 1968 | 2008 | 2040 | 2064 | 2080 | 2088 | 2088 | 2080 | 2064 | 2040 | 2008 | 1968 | 1920 |
| 38  | 1348 | 1440 | 1524 | 1600 | 1668 | 1728 | 1780 | 1824 | 1860 | 1888 | 1908 | 1920 | 1924 | 1920 | 1908 | 1888 | 1860 | 1824 | 1780 | 1728 |
| 39  | 1232 | 1320 | 1400 | 1472 | 1536 | 1592 | 1640 | 1680 | 1712 | 1736 | 1752 | 1760 | 1760 | 1752 | 1736 | 1712 | 1680 | 1640 | 1592 | 1536 |
| 40  | 1116 | 1200 | 1276 | 1344 | 1404 | 1456 | 1500 | 1536 | 1564 | 1584 | 1596 | 1600 | 1596 | 1584 | 1564 | 1536 | 1500 | 1456 | 1404 | 1344 |
| 41  | 1000 | 1080 | 1152 | 1216 | 1272 | 1320 | 1360 | 1392 | 1416 | 1432 | 1440 | 1440 | 1432 | 1416 | 1392 | 1360 | 1320 | 1272 | 1216 | 1152 |
| 42  | 884  | 960  | 1028 | 1088 | 1140 | 1184 | 1220 | 1248 | 1268 | 1280 | 1284 | 1280 | 1268 | 1248 | 1220 | 1184 | 1140 | 1088 | 1028 | 960  |
| 43  | 768  | 840  | 904  | 960  | 1008 | 1048 | 1080 | 1104 | 1120 | 1128 | 1128 | 1120 | 1104 | 1080 | 1048 | 1008 | 960  | 904  | 840  | 768  |
| 44  | 652  | 720  | 780  | 832  | 876  | 912  | 940  | 960  | 972  | 976  | 972  | 960  | 940  | 912  | 876  | 832  | 780  | 720  | 652  | 576  |
| 45  | 536  | 600  | 656  | 704  | 744  | 776  | 800  | 816  | 824  | 824  | 816  | 800  | 776  | 744  | 704  | 656  | 600  | 536  | 464  | 384  |
| 46  | 420  | 480  | 532  | 576  | 612  | 640  | 660  | 672  | 676  | 672  | 660  | 640  | 612  | 576  | 532  | 480  | 420  | 352  | 276  | 192  |
| 47  | 304  | 360  | 408  | 448  | 480  | 504  | 520  | 528  | 528  | 520  | 504  | 480  | 448  | 408  | 360  | 304  | 240  | 168  | 88   | 0    |
| 48  | 188  | 240  | 284  | 320  | 348  | 368  | 380  | 384  | 380  | 368  | 348  | 320  | 284  | 240  | 188  | 128  | 60   | -16  | -100 | -192 |
|   | 3456 | 3264 | 3072 | 2880 | 2688 | 2496 | 2304 | 2112 | 1920 | 1728 | 1536 | 1344 | 1152 | 960  | 768  | 576  | 384  | 192  | 0    | -192 |

Table 1.5: The Profit Table.

## 1.6.2 NEO Personality Inventory Revised (NEO-PI-R)

| Domain Name       | Definition  |
|-------------------|---|
| Neuroticism       | A general tendency to experience negative affects such as fear, sadness, embarrassment, anger, guilt and disgust. Men and woman high on N are also prone to irrational ideas, to be less able to control their impulses, and they cope more poorly than others with stress  |
| Extraversion      | Extraverts (high E) are sociable, they like people and prefer large groups. They like excitement and stimulation, and tend to be cheerful. They are also upbeat, energetic and optimistic. Introversion should be seen as the absence of extraversion, rather than as its opposite                                |
| Openness          | Openness to experience (high O) means active imagination, aesthetic, sensitivity attentiveness to inner feelings, preference for variety, intellectual curiosity and openness to different value systems. Low scores on O tend to be conventional in behavior and conservative in outlook                         |
| Agreeableness     | The agreeableness person (high A) is fundamentally altruistic. He or she is sympathetic to others, eager to help them, and believe that they will be equally helpful in return. Disagreeable (antagonistic) person is egocentric, skeptical of the intentions of others, and competitive rather than cooperative. |
| Conscientiousness | The conscientiousness individual is purposeful, strong-willed and determined, This trait can be also referred as 'will to achieve'. High C are scrupulous punctual and reliable. Low scores are not lacking of moral principles but they are less exciting in applying them.                                      |

The descriptions are based on [Costa & McCrae \(2006, Chapter 5\)](#).

Table 1.6: The five domains of the NEO-PI-R

| Domains               | Facets   |
|-----------------------|--|
| (N) Neuroticism       | (N1) Anxiety<br>(N2) Angry Hostility<br>(N3) Depression<br>(N4) Self-Consciousness<br>(N5) Impulsiveness<br>(N6) Vulnerability |
| (E) Extraversion      | (E1) Warmth<br>(E2) Gregariousness<br>(E3) Assertiveness<br>(E4) Activity<br>(E5) Excitement-Seeking<br>(E6) Positive Emotions |
| (O) Openness          | (O1) Fantasy<br>(O2) Aesthetics<br>(O3) Feelings<br>(O4) Actions<br>(O5) Ideas<br>(O6) Values                                  |
| (A) Agreeableness     | (A1) Trust<br>(A2) Straightforwardness<br>(A3) Altruism<br>(A4) Compliance<br>(A5) Modesty<br>(A6) Tender-Mindedness           |
| (C) Conscientiousness | (C1) Competence<br>(C2) Order<br>(C3) Dutifulness<br>(C4) Achievement Striving<br>(C5) Self-Discipline<br>(C6) Deliberation    |

Table 1.7: *NEO-PI-R Domains and Facets*

### 1.6.3 Screens

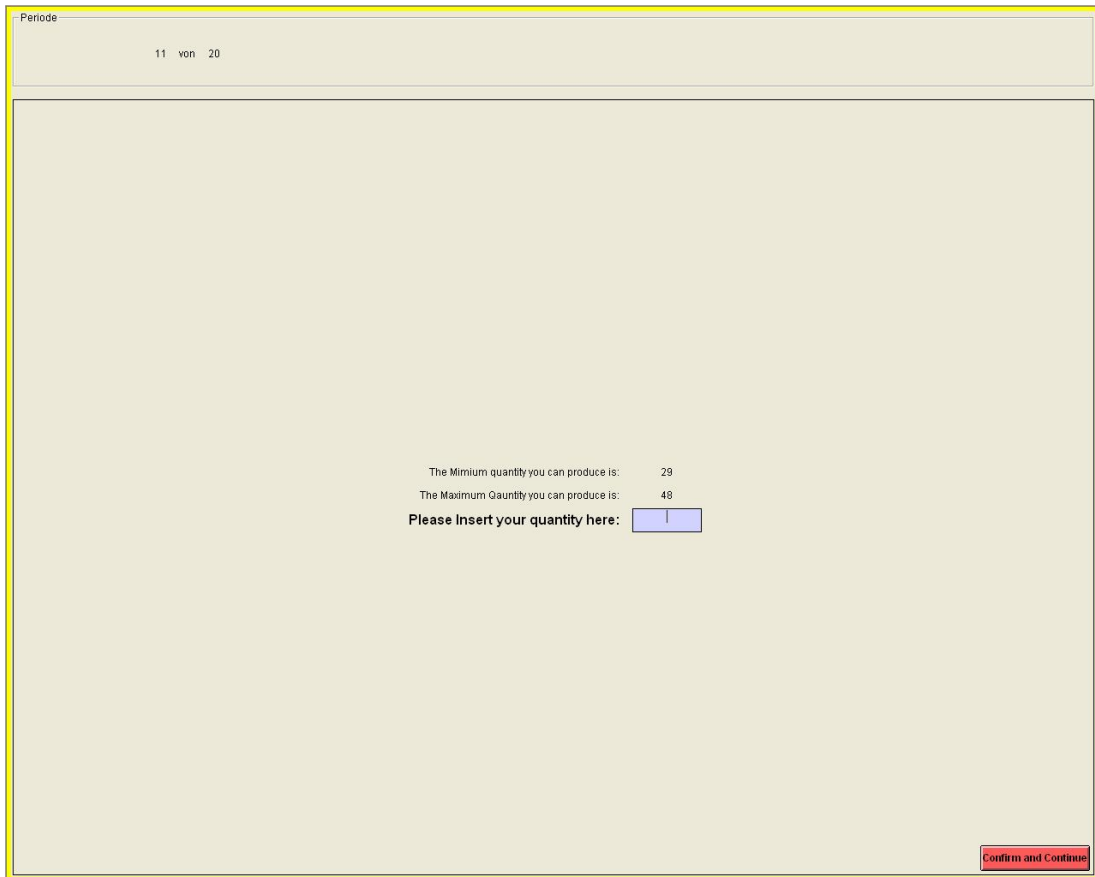


Figure 1.4: The random-matching Cournot duopoly experiment: The ‘decision screen’ in each period.

## 1.6 Appendix to Chapter 1

| Period | Your Quantity | Your Profit | Firm B Quantity | Firm B Profit |
|--------|---------------|-------------|-----------------|---------------|
| 2      | 30            | 1200        | 40              | 3200          |
| 3      | 44            | 2592        | 34              | 912           |
| 4      | 34            | 2272        | 34              | 2272          |
| 5      | 45            | 600         | 45              | 600           |
| 6      | 30            | 240         | 48              | 3364          |
| 7      | 32            | 704         | 45              | 2940          |
| 8      | 32            | 1856        | 36              | 2688          |
| 9      | 29            | 536         | 45              | 3480          |
| 10     | 33            | 2196        | 34              | 2408          |

Figure 1.5: The random-matching Cournot duopoly experiment: The ‘results screen’ after each period. The results of the previous periods are displayed in the bottom of the screen.

### 1.6.4 The size features of hypothesis tests

Ideally, a statistical test should be *exact*. This means that the probability of rejecting the null hypothesis when it is true should be exactly equal to the nominal significance level of the test. However, because of the discreteness of our dependent variable there is a need to verify the size features of the hypothesis tests in use.<sup>20</sup>

Consider a representative linear regression model:

$$y_i = x_{i1}\beta_1 + x_{i2}\beta_2 + \dots + x_{ik}\beta_k + \epsilon_i$$

or in matrix form:

$$\mathbf{y} = \mathbf{X}\boldsymbol{\beta} + \boldsymbol{\epsilon} \quad (1.3)$$

where  $\mathbf{y}$  is the  $N$ -dimensional vector of integer quantities ranging between 29 to 48.  $\mathbf{X}$  is an  $(N \times k)$  dimensional matrix collecting the explanatory variables (including constant),  $\boldsymbol{\beta} = (\beta_0 \dots \beta_k)'$  is a  $k$ -dimensional vector of parameters, and  $\boldsymbol{\epsilon}$  is the error term vector.

It can be shown (see, for example, [Greene, 2003](#), p.51) that if the error term,  $\boldsymbol{\epsilon}$ , is normally distributed, hypothesis testing of a single coefficient (under the null hypothesis  $\beta_j = 0$  for each  $j = 1, \dots, k$ ) is done using the following test statistic:

$$t_k = \frac{\hat{\beta}_j}{s_{\hat{\beta}_j}}, j = 1, \dots, k \quad (1.4)$$

where  $s_{\hat{\beta}_j}$  is the standard error of  $\beta_j$ . This statistic is *student-t* distributed with  $N - k$  degrees of freedom.

A joint significance test of the coefficients in the model (without including the constant) is done using the following  $F$  statistics ([Greene, 2003](#), p.97):

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<sup>20</sup>The bootstrap approach recently suggested by [Herwartz & Xu \(2009\)](#) could correct for inexact result if needed.

$$F = (\mathbf{R}\hat{\boldsymbol{\beta}} - \mathbf{q})' \{ \mathbf{R} [s^2 (\mathbf{X}'\mathbf{X})^{-1}] \mathbf{R}' \}^{-1} (\mathbf{R}\hat{\boldsymbol{\beta}} - \mathbf{q}) / J \quad (1.5)$$

where  $J$  is the number of restrictions,  $\mathbf{R}$  is a  $(J \times k)$  matrix with ones on the diagonal start from the second column of the first row and otherwise zeros<sup>21</sup>.  $\mathbf{q}$  is a  $(1 \times J)$  vector of zeros. The above statistic follows an F distribution with  $J$ ,  $N - k$  degrees of freedom.

Due to the discreteness of our dependent variable we could not assume that the error term in (1.3) is normally distributed, thus we had to verify the size features of the hypothesis tests in use. For this purpose we generated data with similar characteristics to ours, however, we deteriorated the connection between the explanatory variables and the dependent variable. In other words, we generated data *under the null hypothesis of no correlation between the dependent variable and the independent variables*. Hence, we could investigate the rejection probability of the hypothesis tests. In particular, we carried out the following procedure:

1.  $M$  observations  $\{x_{ij}^*\}_{i=1}^M$  ( $M < N = 36$ ) were drawn randomly with replacement from  $\{x_{ij}\}_{i=1}^N$  ( $j = 1, \dots, k$ ). Note that  $N$  is the total number of observation (see Table 1.4). Additionally, we used the values  $M = 30$  and  $M = 20$ .<sup>22</sup>
2.  $M$  observations  $\{y_i^*\}_{i=1}^M$  were drawn randomly with replacement from  $\{y_i\}_{i=1}^N$ ,
3. We determined the OLS estimators  $\hat{\beta}_j^*$ , and computed the  $t$  and the  $F$  statistics for the sample  $\{y_i^*, x_{ij}^*\}$ . Then we compared these statistics with the corresponding Student-t and the F critical values. The null hypothesis is rejected when the  $|t|$  or the  $F$  statistics exceed the  $1 - \alpha/2$  and  $1 - \alpha$  quantiles of the Student-t and F distribution, respectively.

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<sup>21</sup>The specific structure of the  $\mathbf{R}$  matrix aims to test the joint-hypothesis of the model, we exclude the constant since its correlation with the dependent variable is not testable.

<sup>22</sup>The results for  $M=20$  are virtually the same as for  $M=30$ , they can be received from the author upon request.

## 1.6 Appendix to Chapter 1

We repeated steps (2) and (3) 10000 times (such that the  $\{x_{ij}^*\}$  in step 1 were fixed along the procedure). The size estimates are the total number of rejections divided by the 10000 simulations. Table 1.8 presents the size estimates of hypothesis tests (t-tests which measure the significance of each of the five personality domains and gender in explaining performance, and an F-test which measures the joint-significance of all these variables).

| Variable              | Nominal significance level |      |      | Nominal significance level |      |      |
|-----------------------|----------------------------|------|------|----------------------------|------|------|
|                       | 10%                        | 5%   | 1%   | 10%                        | 5%   | 1%   |
|                       | D. Variable: Period 1      |      |      | D. Variable: Period 19     |      |      |
| (N) Neuroticism       | 10.02                      | 5.26 | 1.01 | 10.44                      | 5.30 | 1.18 |
| (E) Extraversion      | 10.00                      | 5.05 | 1.10 | 10.56                      | 5.17 | 1.04 |
| (O) Openness          | 10.20                      | 4.84 | 0.99 | 10.20                      | 5.05 | 1.06 |
| (A) Agreeableness     | 10.39                      | 5.19 | 1.22 | 10.52                      | 5.07 | 1.08 |
| (C) Conscientiousness | 9.91                       | 5.01 | 1.00 | 10.01                      | 5.07 | 1.14 |
| Gender                | 9.48                       | 4.83 | 0.89 | 10.03                      | 5.01 | 1.05 |
| F-test (6, 23)        | 9.88                       | 5.07 | 1.10 | 10.57                      | 5.67 | 1.26 |

Table 1.8: Empirical size estimates for hypothesis tests (according to Table 1.4) in percentage points, for alternative nominal significant levels,  $\alpha = 10\%, 5\%, 1\%$ ,  $M = 30$ , 10000 simulations

Table 1.8 illustrates that empirical size estimates are close to the nominal level of the tests. We can therefore assume that hypothesis tests with our discrete data yield exact results.



## Chapter 2

# Managers and Students Playing Cournot - Experimental Evidence from Malaysia

### 2.1 Introduction

Laboratory experiments in industrial organization are often criticized for using students as subjects. The criticism centers on the issue of whether a sample of students can deliver information about the behavior of firms (or firms' managers). As a consequence, several experiments were designed to test the effect of subject pool selection on subject performance. These experiments came up with ambiguous evidence. While [Cooper \*et al.\* \(1999\)](#), [Montmarquette \*et al.\* \(2004\)](#), and [Ball & Cech \(1996\)](#) find little or no difference in performance between managers and students, [Fehr & List \(2004\)](#), [Alpízar \*et al.\* \(2004\)](#), and [Cooper \(2006\)](#) find that in particular situations managers behave more cooperatively than students.

The classical quantity-setting (Cournot) oligopoly is a prominent example of strategic interaction among firms. Due to its simplicity, it is the subject of numerous experimental studies. Despite the focus on firms' behavior, the external validity of Cournot experiments conducted with students has never been challenged by conducting similar experiments with managers.

[Huck \*et al.\* \(2004\)](#) designed a series of experiments that comprise the common features of most Cournot studies. Using student subjects they find that although

## 2.2 Experimental Design and Procedure

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participants in a duopoly sometimes collude, this rarely occurs in the market with more than two firms. In addition, they find that the Nash equilibrium is a quite accurate predictor for subject performance in a Cournot triopoly.

Since the experimental evidence by [Fehr & List \(2004\)](#), [Alpizar \*et al.\* \(2004\)](#), and [Cooper \(2006\)](#) suggests that managers show more collusive behavior than students, we replicate the design of [Huck \*et al.\* \(2004\)](#) in order to test whether the use of student subjects instead of managers in a Cournot triopoly experiment is sensible with regard to external validity. In particular, this study compares the performance of middle and high-ranking Malaysian managers mainly from the manufacturing industry with Malaysian and German undergraduate students.

Our findings support those studies suggesting that managers perform more cooperatively than students. We also find that the country matters (i.e. German students perform more cooperatively than Malaysian students), while gender affects the outcome differently in Germany and Malaysia.

## 2.2 Experimental Design and Procedure

We adopt the design of [Huck \*et al.\* \(2004\)](#) for the triopoly case, but we use different subject populations: German students, Malaysian students, and Malaysian managers.

### 2.2.1 The underlying model and design

In particular, we set up a symmetric Cournot triopoly<sup>1</sup> with a homogeneous product and fixed matching lasting over 25 periods. Communication between the firms (subjects) is not allowed; the feedback after each period contains only aggregate information about the other firms' performance.

The firms are acting in a market with the following demand function:

$$P(Q) = \max \{100 - Q, 0\}, \quad (2.1)$$

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<sup>1</sup>As in most oligopoly experiments, the situation was economically framed.

## 2.2 Experimental Design and Procedure

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where  $Q = \sum_{i=1}^3 q_i$ . The cost function for each seller is

$$C(q_i) = q_i \quad (2.2)$$

Under this setting, the Nash equilibrium market quantity is  $Q^N = 74.25$ , whereas the symmetric collusive (monopolistic) quantity is given by  $Q^M = 49.5$ , and the competitive quantity by  $Q^C = 99$ .

Subjects could select quantities between 1 and 100 in steps of 0.01. In each period the subjects were allowed to use a profit calculator for simulating their own and the other firms' decisions before taking the real-output decision.

### 2.2.2 Subjects recruitment and control

We recruited 33 undergraduate students from the University of Kiel, Germany, and 39 undergraduate students from University Sains Malaysia.<sup>2</sup> Additionally, we invited 33 Malaysian managers from small and medium-size firms mainly from the manufacturing industry (plastics, cable assemblers, chip manufacturers, and computer parts manufacturers) in Penang Island, West Malaysia, to participate in the experiment. Target companies were sourced from the Federation of Malaysian Manufacturers (FMM) directory, which lists all the small and medium size firms (SME) in Penang state. A letter of invitation was sent to the company secretary asking him/her to forward it to the relevant person in the company.<sup>3</sup> Manager age ranged between 29 and 54, most of them around 35. All of them had at least a Bachelor's degree and two of them a PhD. As they had Malaysian citizenship, the ethnicity of the managers was Chinese (90.9%) and Indian. The estimated earnings of the selected group ranged between 4000 RM and 9000 RM per month, with an estimated average of 5000-6000 RM.<sup>4</sup>

The subjects participating in the three treatments had not previously participated in an experiment. The experiment was programmed and conducted using

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<sup>2</sup>Most students in Germany and Malaysia were recruited from Economics courses.

<sup>3</sup>We did not reveal the nature of the experiment, merely that it was a computer-based experiment designed to analyze decision-making. We also announced the expected payoff range.

<sup>4</sup>5000-6000 RM  $\approx$  1500-1900 US\$.

the z-Tree (Fischbacher, 2007) experimental program. In all treatments we followed the same procedure, and used the same experimenter.<sup>5</sup> The experiment was explained and conducted in English (in Malaysia) and German. The instructions (based on an English translation of Huck *et al.*, 2004) were carefully inspected by the experimenters (one is linguistically and culturally fluent in Malaysian English, the other is in German). Regarding the *currency effect*, the payment was calculated to have a similar purchasing power across countries, so that a German student choosing the Nash equilibrium quantity along the experiment (given that the whole industry also decides on the Nash equilibrium quantity) earns €15. Under similar conditions, a Malaysian student earns 9.5 RM.<sup>6</sup>

## 2.3 Results

Following the approach of Huck *et al.* (2004), we start by averaging market quantities over time. This approach allows us to explore the average performance of each oligopoly market. Second, in order to figure out the time-series properties of the data, we average market quantities at each time period. Last, we inspect the pooled data across markets and over time.

### 2.3.1 The effect of subject pool on performance

|                   | German Students | Malaysian Students | Malaysian Managers |
|-------------------|-----------------|--------------------|--------------------|
| $\bar{Q}_{1-25}$  | 74.66 (5.19)    | 80.83 (8.85)       | 75.91 (4.88)       |
| $\bar{Q}_{17-25}$ | 76.18 (5.79)    | 81.25 (6.93)       | 76.21 (4.94)       |
| $\bar{Q}_{5-20}$  | 75.51 (5.81)    | 80.05 (9.16)       | 75.96 (5.08)       |

Table 2.1: Mean (and standard deviation) of the market quantities averaged over time.  $\bar{Q}_{1-25}$  is the average over all periods,  $\bar{Q}_{17-25}$  is the average over the last 9 periods,  $\bar{Q}_{5-20}$  is the average over the middle 16 periods.

<sup>5</sup>We followed the procedure of Roth *et al.* (1991) concerning the cross-country aspects.

<sup>6</sup>On the one hand, a vegetarian sandwich and a bottle of Coca-Cola cost about 3 RM at the University Sains Malaysia campus, in comparison with about €3.5 at the University of Kiel Campus. On the other hand, students' earnings per hour (alternative cost) are about 3.5 RM in Penang in comparison with about €6.5 in Kiel. The payment is a weighted average of these two examples.

Table 2.1 presents the market quantities averaged over all periods, over the last 9 periods, and over the intermediate 16 periods (periods 5 to 20, in order to exclude beginning and end effects). Table 2.1 suggests that the averaged quantity selected by the Malaysian students is larger than the average quantities selected by both the Malaysian managers and the German students. Formally, using a Flinger and Policello robust rank order test (F-P test) we find that the median quantity selected by the Malaysian students is different from the median quantity selected by each of the other two samples at the 5% s.l. Also, we cannot reject the null hypothesis that the median quantities selected by the German students and the Malaysian managers are not different from the Nash equilibrium quantity of 74.25, but we reject this hypothesis for the Malaysian student sample.<sup>7</sup>

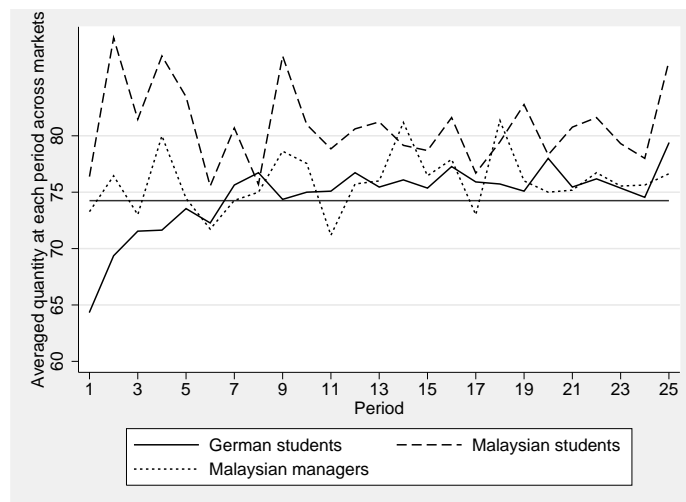


Figure 2.1: Quantities averaged across oligopoly markets at each time period (a total of 25 periods). The straight line denotes the Nash equilibrium quantity, 74.25.

Regarding analysis over time, Figure 2.1 presents the quantities at each time period, averaged across oligopoly markets. The most prominent inspection from that figure is that at almost every time period the averaged quantities across markets selected by the Malaysian students are larger than the quantities selected

<sup>7</sup>In addition, using an F-P test we confirm that the results by [Huck et al. \(2004\)](#) in Berlin are indistinguishable from our result in Kiel (2007) at the 10% s.l.

by the other two samples. Formally, using an F-P test we find that the quantities selected by Malaysian students are different from the quantities selected by Malaysian managers and German students at the 1% s.l., respectively. In addition, we observe a significant time-trend in the initial periods of the German student treatment. This time-trend vanishes already after six periods.<sup>8</sup> By contrast, no significant time-trend is observed in the Malaysian treatments.

Finally, we pool the data across oligopoly markets and over time. Figure 2.2 presents the histograms of the pooled quantities in each treatment. Using a t-test, we cannot reject the null hypothesis that the mean quantity selected by the German students is not different from the Nash equilibrium level of 74.25 at the 10% s.l. However, we reject this hypothesis for the Malaysian samples (at the 1% s.l. for the Malaysian student sample and at the 5% s.l. for the Malaysian manager sample).

|                                   | German Students | Malaysian Students | Malaysian Managers |
|-----------------------------------|-----------------|--------------------|--------------------|
| Average quantity                  | 74.64           | 80.81              | 75.91              |
| Across-market analysis            | n.d             | d. at 5%           | n.d                |
| Over-time analysis                | n.d             | d. at 1%           | d. at 1%           |
| Pooled-data analysis <sup>9</sup> | n.d             | d. at 1%           | d. at 5%           |

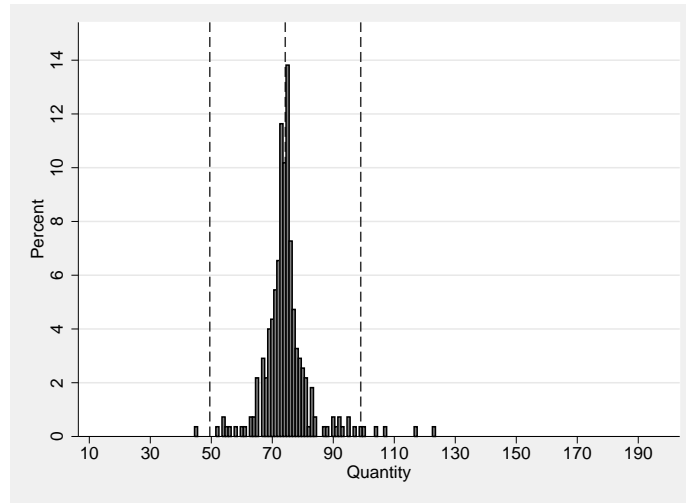
Table 2.2: Results of a one sample Wilcoxon sign rank test to find whether the median quantities in the three treatments are statistically different from the Nash equilibrium quantity of 74.25. “n.d” denotes “no difference” at the 10% s.l, “d” denotes “significant difference” at a 10% s.l. or lower.

To sum up, Table 2.2 presents the results of a one-sample Wilcoxon sign rank test and a t-test on whether triopoly markets perform at the Nash equilibrium level. Accordingly, we can formulate:

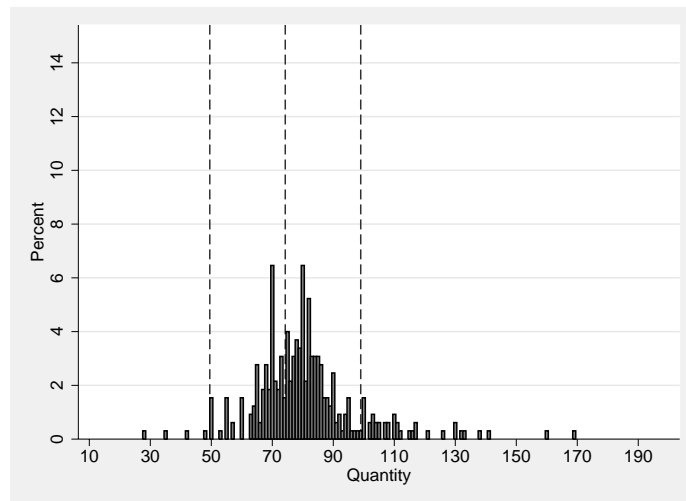
**Result 1:** *The Nash equilibrium is a quite accurate predictor for performance in triopoly markets conducted with German students. By contrast, we reject the hy-*

<sup>8</sup>Like Huck *et al.* (2004), we verified the time-trend by regressing the averaged quantities on time. Huck *et al.* (2004) also observed a time-trend, however, in their case it vanishes after four periods.

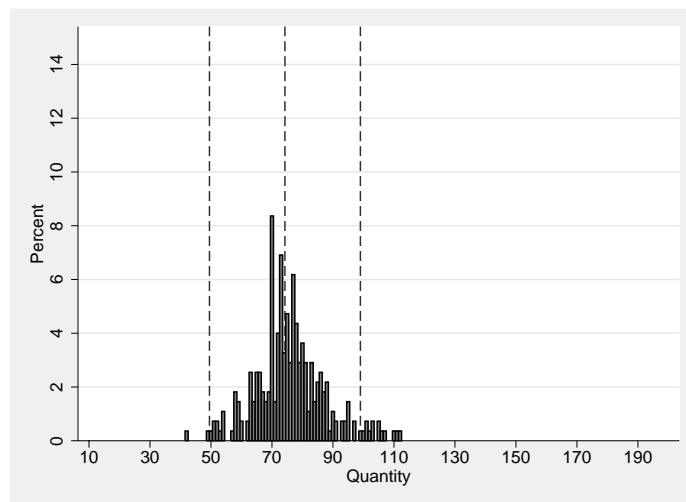
<sup>9</sup>A T-test was also performed on the pooled regression. The results confirm the median test.



(a) German student treatment



(b) Malaysian student treatment



(c) Malaysian manager treatment

Figure 2.2: Histograms of the quantities pooled across oligopoly markets and over time. The dashed lines denote the benchmark quantities: 49.5 is the cooperative quantity, 74.25 is the Nash quantity, and 99 is the competitive quantity.

*pothesis that both the Malaysian students and managers select the Nash quantity.*

| Test                                  | Difference between Treatments                                |
|---------------------------------------|--|
| Median test                           | Malaysian students * > Malaysian managers = German students  |
| Variance test                         | Malaysian students = Malaysian managers = German students    |
| (a) Analysis across Oligopoly Markets |  |
| Test                                  | Difference between Treatments                                |
| Mean test                             | Malaysian students > Malaysian managers = German students    |
| Median test                           | Malaysian students > Malaysian managers = German students    |
| Variance test                         | Malaysian students = Malaysian managers = German students    |
| (b) Analysis over Time                |  |
| Test                                  | Difference between treatments                                |
| Mean test                             | Malaysian students > Malaysian managers = German students    |
| Median test                           | Malaysian students > Malaysian managers = German students    |
| Variance test                         | Malaysian students ** > Malaysian managers > German students |
| (c) Analysis of Pooled Data           |  |

Table 2.3: The result of a mean test (t-test), a median test (Wilcoxon sign rank test and Flinger and Policello Robust rank order test), and a variance test (Siegel-Tukey test) testing whether the quantities selected in the three treatments differ from each other. The symbols =, >, \* >, and \*\* > denote no difference at the 10% significant level, difference at the 1%, 5%, and 10% s.l., respectively.

Table 2.3 presents the results of statistical tests regarding differences in performance between subject pools. We can now formulate the next result.

**Result 2:** *Malaysian students perform more competitively than both Malaysian managers and German students.*



### 2.3.2 The effect of gender on performance

Table 2.4 presents the mean quantity (and standard deviation) according to gender in each sample.<sup>10</sup> Using a t-test, we find that the mean quantity selected by German females is smaller (less competitive) than the mean quantity selected by German males at the 1% s.l. Using the same procedure for the Malaysian treatments, we find that for both samples Malaysian males are less competitive than Malaysian females.<sup>11</sup> These findings are reflected in the Pearson correlation coefficient between male gender and the quantity selected by the subjects. For the German sample it equals 0.22, whereas for the Malaysian students and managers it is equals  $-0.13$  and  $-0.15$ , respectively (all the results being significant at the 1% level). Accordingly, we can portray result 3.

**Result 3:** *In Germany and Malaysia gender affects subject performance in opposite directions. German males are more competitive than German females, while Malaysian males behave less competitively than Malaysian females.*

| Treatment          | Males         | Females       |
|--------------------|---------------|---------------|
| German students    | 26.63 (5.92)  | 24.00 (4.81)  |
| Malaysian students | 25.06 (10.67) | 28.55 (14.80) |
| Malaysian managers | 24.51 (8.91)  | 26.50 (8.72)  |

Table 2.4: The mean (and standard deviation) of the selected individual quantities, differentiated with respect to gender in the different treatments.

### 2.3.3 The profit calculator

In order to obtain further insights about subject behavior in the three treatments we inspect the ‘profit-calculator’ data. Pooling the data across subjects and over time and using a total of 2625 observations, we find that use intensity of the profit calculator (number of calculations per period) is negatively correlated with the

<sup>10</sup>The analysis in this section is based on the pooled data across subjects (firms) and over time.

<sup>11</sup>Significant at the 1% s.l.

output decision.<sup>12</sup> A possible interpretation of this result is that subjects who decide to play collusively act in a more thoughtful way.

We also verify that the larger the average hypothetical quantity fed into the profit calculator in a given period, the larger the actual quantity selected by the subject at that period.

## 2.4 Concluding Remarks

This study confirms the findings by [Huck \*et al.\* \(2004\)](#) that, by and large, the Cournot-Nash equilibrium is a good predictor for subject performance in Cournot triopoly experiments (at least, the quantities selected by the three subject pools are closer to the Nash quantity than to the other two benchmark quantities). However, while German students follow the Cournot strategy almost perfectly, the Malaysian subjects' quantities (both students' and managers') are significantly different from the Cournot-Nash quantity. Furthermore, we find that the Malaysian students perform more competitively than the Malaysian managers, a result consistent with the previous studies by [Fehr & List \(2004\)](#), [Alpizar \*et al.\* \(2004\)](#), and [Cooper \(2006\)](#).

Finally, we find that gender does affect subject performance. Regarding the German student sample, we find that females behave more cooperatively than males<sup>13</sup>, while the opposite holds for the Malaysian samples. This result supports findings by [Gneezy \*et al.\* \(2009, forthcoming\)](#) suggesting that societal structure is crucially linked to observed gender differences in behavior.

## Acknowledgements

We are grateful to Jörg Oechssler, Steffen Huck, and Hans-Theo Normann for providing us with the computer program used in [Huck \*et al.\* \(2004\)](#). We are grateful for helpful comments from participants in the ESA European regional meeting in Lyon.

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<sup>12</sup>Pearson's correlation coefficient is equal to  $-0.07$ ; it is significant at the 1% level.

<sup>13</sup>This result is in line with the study by [Mason & Phillips \(1991\)](#) (conducted with American students), who find that females cooperate more than males in a Cournot duopoly.

## 2.5 Appendix to Chapter 2

### 2.5.1 Instructions

- Welcome to our experiment. Please read these instructions carefully! From now until the end of the experiment you are not allowed to communicate with the other participants. If you have any questions, please raise your hand, and we will answer them Individually.
- At the beginning of the experiment, each one of you will be assigned a number. From then on, you and the other participants will be identified by this number. Please keep it until you receive your payment. In addition, there are two empty sheets of paper that you can use during the experiment.
- In this experiment you will repeatedly be asked to make decisions that can earn you a reasonable amount of money. How much you earn depends not only on your decisions but also on the decisions of the other participants.
- All participants receive the same instructions.
- In this experiment you represent a firm that produces and sells the same product, as two other firms, in the market. You will be matched with the same two firms during the whole experiment.
- You will stay anonymous for the other firms, both during and after the experiment.
- In each period all firms have to make one decision, namely what quantity they wish to produce.
- The cost of production is 1 ECU (Experimental Currency Unit) per unit (this holds for all firms).
- The following important rule holds: The higher the total (aggregate) quantity produced by all firms, the lower the price in the market. Moreover, from a certain amount of total output upwards the price will be zero.

- Your profit per unit of output will be the difference between the market price and the unit cost of 1 ECU. Note that you will make a loss if the market price is below the unit cost. Your profit per period is thus equal to the profit per unit multiplied by the number of units you sell.
- During the experiment you can use a ‘profit calculator’ before you decide on the quantity to produce. You enter your quantity and the total (aggregate) quantity of the other two firms and the ‘profit calculator’ will calculate your earnings.
- In each period, the output decisions of the other two firms will be registered, the corresponding price determined, and the profits computed.
- After each period, you will get information on your screen about the quantity chosen by you, the aggregate quantity chosen by the other two firms, your payoff in the current period, and your commutative payoff starting from the first period.
- The experiment consists of exactly 25 periods.
- During the experiment, all payoffs are given in ECU. Each participant starts with an initial amount of 500 ECU.
- After the experiment we will convert your payoff to RM. The exchange rate is 66.5 ECU/RM, that is, 66.5 ECU is equal to 1 RM.<sup>14</sup>
- Your total profit in the experiment is the total amount you earned in the 25 periods of the experiment (plus the initial amount of 500 ECU).
- At the end of the experiment we will calculate your money payoff reward. This will be done in way that ensures that the other participants will not see how much you earned and you will not see how much they earned. You will receive your money immediately in cash.

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<sup>14</sup>The currencies and the exchange rates differed across treatments.

2.5.2 Screens

Round: 1 out of 25 Remaining time [sec]: 0

Please reach a decision!

| Profit Calculator                     |               |              |
|---------------------------------------|---------------|--------------|
| Aggregate quantity of the other firms | Your Quantity | Your payment |
| 23.00                                 | 23.00         | 1219.00      |
| 24.00                                 | 23.00         | 1196.00      |
| 25.00                                 | 23.00         | 1173.00      |
| 30.00                                 | 23.00         | 1058.00      |
| 50.00                                 | 23.00         | 598.00       |
| 99.00                                 | 23.00         | -23.00       |
| 23.00                                 | 24.00         | 1248.00      |
| 16.00                                 | 16.00         | 1072.00      |

Choose quantity to produce

Here you can simulate your decision to see all possible consequences:

Your quantity

Aggregate quantity of the other firms

Compute OK

Figure 2.3: The Cournot Triopoly experiment: The ‘decision screen’ in the first period. The profit calculator appears in the left-hand side of the screen, while subjects select their quantities in the right-hand side.

## 2.5 Appendix to Chapter 2

Round: 2 out of 25 Remaining time [sec]: 0

Please reach a decision!

| Aggregate quantity of the other firms | Your quantity | Your payment |
|---------------------------------------|---------------|--------------|
| 13.00                                 | 12.00         | 888.00       |
| 13.00                                 | 12.00         | 888.00       |
| 16.00                                 | 16.00         | 1072.00      |

**Results of the previous round**

Your quantity: 28.00  
Aggregate quantity of the other firms: 46.00  
Your payment: 700.00  
Your total payment so far: 1200.00

Here you can simulate your decision to see all possible consequences:

Your quantity:   
Aggregate quantity of the other firms:

Choose quantity to produce:

Compute OK

Figure 2.4: The Cournot Triopoly experiment: The ‘decision screen’ from the second period on. The profit calculator appears in the left-hand side of the screen, while the results of the previous period are displayed in the upper part of the right-hand side. Subjects select their quantities in the bottom part of the right-hand side.

## Chapter 3

# Investment Incentives Under Emissions Trading: An Experimental Study

### 3.1 Introduction

Policy-makers are often required to make a selection among different policy instruments for protecting the environment. In this field, it is meanwhile widely acknowledged that ‘market-based’ pollution control instruments, such as emission taxes and tradable permits, are powerful and efficient tools to regulate pollution. Early on, [Kneese & Schultze \(1975\)](#) emphasized that, among all available criteria to judge the efficiency of the different pollution control policies, one of the most important is the extent to which a given policy encourages firms to develop or adopt low-pollution technologies. Since then, a large avenue of research started to analyze, from theoretical and empirical viewpoint, the impact of different policy instruments on technological change. The first attempts to rank environmental policy instruments, taking the adoption of advanced technology as an efficiency criterion, were made by [Downing & White \(1986\)](#), [Malueg \(1989\)](#), and [Milliman & Prince \(1989\)](#).<sup>1</sup> Using aggregate cost saving as investment criteria, these studies, however, focus on the effect on the whole industry and not on the in-

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<sup>1</sup>See [Requate \(2005\)](#) for a survey about incentives provided by environmental policy instruments to adopt and develop advanced abatement technology.

centives of a single firm to adopt the new technology. Consequently, [Kennedy & Laplante \(2000\)](#) and [Requate & Unhold \(2001, 2003\)](#) (for the case of adoption of new technology), and [Montero \(2002a,b\)](#) and [Fischer \*et al.\* \(2003\)](#) (for the case of technology innovation) suggested that equilibrium considerations should be taken into account when studying the incentives to adopt (or develop) new technology. In other words, the number of firms that adopt the new technology in equilibrium should be endogenously determined.

Since [Plott's \(1983\)](#) first laboratory experiment on emission trading, numerous experimental studies have been published on permit trading.<sup>2</sup> However, only a few considered the adoption of advanced technology in permit markets. [Ben-David \*et al.\* \(1999\)](#) considered a market where firms are producing a good using capital and permits. In their setting, firms can use one of three possible production technologies where permits and capital costs are inversely related (i.e. the cleanest technology is the most expensive in terms of capital). Each period the firms choose their technology for the next period (however, choosing a 'cleaner' technology is irreversible). [Ben-David \*et al.\* \(1999\)](#) introduce heterogeneity via the marginal abatement cost of switching from one technology to another. They find that heterogeneity leads to lower efficiency from trade. [Hizen \*et al.\* \(2001\)](#) and [Kusakawa & Saijo \(2003\)](#) investigated emission trading using either bilateral trading, or double auction. They define investment irreversibility such that when a firm is abating one unit of emission and then emitting this unit, it incurs a cost. They find that investment irreversibility and time lag in abatement reduce efficiency. Finally, [Gangadharan \*et al.\* \(2005\)](#) examine the interaction between banking of permits and (irreversible) investment in a cleaner technology. They consider a market with six types of firms differing with respect to production capacity and cleanliness, when production capacity and cleanliness are inversely related. Permits were freely allocated to those firms, which could relocate them through a double auction. Moreover, the firms could invest a fixed amount, the same for all types, to produce more for the same amount of pollution emitted. The effect of investment, however, is asymmetric, such that dirty firms gain more by investing. [Gangadharan \*et al.\* \(2005\)](#), in contrast to our design, held the amount of pollution emitted fixed and varied the quantity of output produced. Additionally, information about investment was announced publicly in their ex-

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<sup>2</sup>A summary of the literature is given in [Muller & Mestelman \(1998\)](#) and in [Bohm \(2003\)](#).



periment. They find that firms tend to over-invest and over-bank. In other words, not only ‘dirty’ firms invest in advanced technology but also ‘cleaner’ firms that could otherwise invest in more productive alternatives. The result is sub-optimal market efficiency.

This paper centers on the case investigated by [Requate & Unhold \(2001\)](#), when the regulator takes into account the potential technological change when deciding on the environmental policy to be applied. This is the case of the European countries as a result of the application of the Integrated Pollution Prevention and Control (IPPC) Directive 96/61. The IPPC legislation requires emission reduction and environmental improvements on the basis of what is achievable with the best techniques available to individual industrial sectors. The analysis of [Requate & Unhold \(2001\)](#) in the case of industry characterized by many (a continuum of) asymmetric firms demonstrates that in a subgame perfect equilibrium when the regulator sets the optimal Pigouvian tax, or alternatively, issues the optimal number of permits the share of firms adopting the new technology is socially optimal.

Testing the behavior of firms in the laboratory under a Pigouvian tax<sup>3</sup> does not make much sense, since even when a firm deviates from the theoretical allocation it does not affect the maximization considerations of the others. However, this is not the case when the government issues emission permits, since expectations about the price of permits depend on the other firms’ behavior. Thus, auctioned permits may yield different results than grandfathered permits. This study tests, in the laboratory, the theoretical findings of [Requate & Unhold \(2001\)](#) that in an industry characterized by many small asymmetric firms, when the regulator issues the socially optimal number of permits, auctioning and grandfathering provide the same incentives to invest in advanced technology. Although [Requate & Unhold \(2001\)](#) did not specify an auction design, we investigate the behavior of firms under two allocation policies (free allocation of permits also called grandfathering vs. auctioned permits) and under two different auction designs (ascending clock auction vs. single unit double auction). Besides testing the investment behavior, we evaluate the efficiency of the policies in allocating permits and in maximizing the total social welfare of the economy. Moreover, we employ the low-payoff menu of paired lottery ([Holt & Laury, 2002](#)) to see whether attitudes towards risk affect

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<sup>3</sup>Under the condition of perfect information.

subjects' performance in the laboratory.

Our results confirm Requate and Unholds' proposition that auctioning and grandfathering do not yield different results regarding investment in advanced abatement technology. In particular, the different treatments yield similar results regarding investment in advanced abatement technology and regarding the total social welfare of the economy. However, regarding efficiency in allocation of permits, the double auction outperforms the ascending clock auction.

This paper is organized as follows: In Section 3.2 we present the theoretical model. In section 3.3 we describe the experimental design and procedure. In Section 3.4 we present the results. Section 3.5 concludes.

## 3.2 Theoretical Background

This section portrays the theoretical model serving as a basis for our experiment. The model outlined here is a discrete version of the model proposed by [Requate & Unhold \(2001\)](#).

Let us consider an industry consisting of  $n$  polluting firms, and  $K$  different initial technologies. Each firm  $i = \{1, \dots, n\}$  is endowed with one of these initial technologies and can invest to adopt the advanced technology  $a$ , the same for all firms. The firms' technologies are represented by their abatement cost function  $C^i(e_i, k)$  with  $k = 1, \dots, K, a$ . We assume that for any targeted emission level  $e$  we have  $C^i(e, k) > 0$  for  $e < \bar{e}_k$ , where  $\bar{e}_k$  is the baseline emission level of technology  $k = 1, \dots, K$ . Investment in advanced abatement technology leads to both lower abatement and lower marginal abatement costs, i.e.  $C^i(e, k) > C^i(e, a) > 0$  and  $-C_e^i(e, k) > -C_e^i(e, a)$  for all  $e \leq \bar{e}_k$ , where  $-C_e^i(e, k) = -\partial C_e^i(e, k)/\partial e$  is the marginal abatement cost. We denote by  $k(i)$  the technology initially owned by firm  $i$ . Without a loss of generality we assume that the firms' abatement cost functions are ordered from the dirtiest to the least dirty:  $C^i(e, k(i)) \geq C^{i+1}(e, k(i+1))$  and  $-C_e^i(e, k(i)) \geq -C_e^{i+1}(e, k(i+1))$ . Installing the new technology causes a fixed cost,  $F > 0$ , for simplicity it is the same for all firms. Moreover, when setting the optimal policy, the regulator uses an increasing and convex social damage function,  $D(E)$ , that evaluates emissions in monetary terms, where  $E = \sum_{i=1}^n e_i$  denotes aggregate emissions.

A social planner minimizes total social costs with respect to emissions and

## 3.2 Theoretical Background

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the number of firms. When the fixed investment cost is independent of the initial technology, it is always optimal that, if not all firms are supposed to adopt the advanced technology, at least those firms with the highest abatement costs should invest, i.e. there will be some index  $j$ , such that the firms  $i = 1, \dots, j$  will invest. Exploiting that  $C^i(e_i, a) = C^j(e_j, a)$  and  $e_i = e_j$  for all  $i \leq j$ , the social planner's problem can therefore be written as:

$$\min_{\{j, e_1, \dots, e_j, e_a\}} \{j[C^j(e_j, a) + F] + \sum_{i=j+1}^n C^i(e_i, k(i)) + D(E)\}$$

where  $E = je_j + \sum_{i=j+1}^n e_i$ . Clearly for  $i > j$ ,  $e_i$  depends only on the type of technology  $k$ .

Denoting the optimal *aggregate marginal abatement cost* when the first  $j$  firms have adopted the advanced abatement technology by  $AMAC^*(E, j)$ , the regulator will choose the optimal aggregate emission level,  $E^*$ , satisfying

$$D'(E^*) = AMAC^*(E^*, j) \quad (3.1)$$

We assume that a regulating authority uses tradable permits to control emissions. Therefore, it will issue of a number of permits,  $L = E^*$ , to enforce the aggregate emission level  $E^*$ . Denoting the market price for permits by  $\sigma$ , a firm with technology  $i$  chooses an emission level  $e_i(\sigma)$  such that its marginal abatement cost equals the price of permits:  $-C'_i(e_i(\sigma)) = \sigma$ .

Now a firm with original technology  $i$  has an incentive to adopt the advanced technology  $a$  if:

$$C^i(e_i(\sigma, a), a) + F + \sigma[e_i(\sigma, a) - \hat{e}_i] < C_i(e_i(\sigma, k), k) + \sigma[e_i(\sigma, k) - \hat{e}_i] \quad (3.2)$$

where  $\hat{e}_i$  is firm  $i$ 's initial endowment of permits, if there is any. Condition (3.2) indicates that investment is profitable if the total cost consisting of abatement cost, expenditures on permits, and investment cost is lower than the abatement cost plus expenditures for permits without investment. This condition depends crucially on the permits' price. Even for identical firms it can be the case that in equilibrium some firms adopt the new technology and some do not (see [Requate](#)

### 3.3 Experimental Design and Procedure

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& Unhold, 2003). In fact, the price of permits and the number of firms are both determined endogenously. These authors show that the socially optimal allocation can be theoretically implemented, by issuing the *ex-ante* socially optimal number of emission permits for both, a completely symmetric model (see Requate & Unhold, 2003), and an asymmetric model (see Requate & Unhold, 2001). In our experimental study, we therefore assume that the regulator issues the optimal number of permits. Requate & Unhold (2001, 2003) also show that the social optimum can be decentralized irrespective of permits being allocated for free (grandfathered) or being auctioned off. In these papers, the auction design is not specified. It is just assumed that the auction induces the competitive market clearing price.

### 3.3 Experimental Design and Procedure

This section thoroughly describes the experimental design and procedure. The experiment was programmed and conducted using the z-Tree experimental software (Fischbacher, 2007) and was held at the experimental laboratory of the University of Kiel. We aim at testing the theoretical predictions by Requate & Unhold (2001) by issuing the *ex-ante*, socially optimal number of emission permits, and hypothesize that the socially optimal level of investment would be achieved regardless of (i) the way emission allowances are initially allocated, and of (ii) the auction design. We therefore conduct several treatments, varying the way of initial allocation (free vs. costly) and varying the auction design.

Typically, under a system of grandfathering, firms can bilaterally trade permits. To mimic this it is natural to implement a single unit double (oral) auction. Under the so called auctioning-system of permits, several designs are possible. We chose an ascending clock auction because of its simplicity. By doing so, two features are different between the treatments: The allocation mechanism and the auction design. Thus, in order to investigate the effect of the initial allocation of permits, or of the auction design on firms' performance, we had to conduct a treatment with only one feature different from each of the other two treatments. Therefore, we conducted an additional treatment where permits are initially allocated for free, but the price is determined by an ascending clock auction.

Furthermore, we conducted two types of treatments, the single-period and

### 3.3 Experimental Design and Procedure

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the multi-period treatments. The single-period treatments consist of two phases: In the first phase subjects decide whether or not to invest and in the second phase they participate in an auction. This auction will determine their number of permits and, thus, their emission level (=abatement level). In the real world, however, investment does not always happen simultaneously. Firms might first wait and observe the other firms' behavior, and only then decide whether or not to invest in the new technology. In this sense, we conducted a further series of treatments where the relevant time horizon is four periods. As in the single-period treatments each period consists of two phases: In the first phase subjects decide whether or not to invest (only if they did not invest in the previous periods), and in the second phase they participate in an auction. We refer to these treatments as the multi-period treatments. In total we refer to the different treatments as follows:

- SAAC = single period auctioning off permits through an ascending clock auction
- SGAC = single period grandfathering and relocating permits through an ascending clock auction
- SGDA = single period grandfathering and relocating permits through a single unit double auction
- MAAC = multi period auctioning off permits through an ascending clock auction
- MGDA = multi period grandfathering and relocating permits through a single unit double auction

The SGAC treatment was conducted to investigate whether possible differences in performance between the policy instruments are due to the initial allocation of permits or due to the choice of auction design. Since we did not observe a difference between the instruments, we did not conduct a multi-period treatment with grandfathering and ascending clock auction

We consider an industry consisting of 18 firms of five different types  $k = \{T_1, \dots, T_5\}$  characterized by their marginal abatement technologies. In each period each firm earns an unconditional default profit of  $\Pi^0 = 1200$ . The fixed

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investment cost is  $F = 580$  in the single-period, and  $F = 2000$  in the multi-period treatments. Profits are indicated in experimental currency units (ECU), which were then converted into € at an exchange rate of ECU40=€1 in the single-period treatments, or ECU160=€1 in the multi-period treatments. Finally, we set the social damage function by  $D(E) = E^2/4$ , leading to the marginal damage  $E/2$ , where  $E = \sum_{i=1}^{18} e_i$  denotes aggregate emissions.<sup>4</sup> The marginal abatement technologies of the different types are given in Table 3.1, while the number of firms and the allocation of permits (in the treatments with grandfathering) per type are given in Table 3.2.

| MAC | Emissions ( $e_i$ ) per technology type |       |       |       |       |     |
|-----|---|-------|-------|-------|-------|-----|
|     | $T_1$                                   | $T_2$ | $T_3$ | $T_4$ | $T_5$ | $a$ |
| 0   | 20                                      | 18    | 16    | 14    | 12    | 7   |
| 10  | 19                                      | 17    | 15    | 13    | 11    | 6   |
| 20  | 18                                      | 16    | 14    | 12    | 10    | 5   |
| 30  | 17                                      | 15    | 13    | 11    | 9     | 4   |
| 40  | 16                                      | 14    | 12    | 10    | 8     | 3   |
| 50  | 15                                      | 13    | 11    | 9     | 7     | 2   |
| 60  | 14                                      | 12    | 10    | 8     | 6     | 1   |
| 70  | 13                                      | 11    | 9     | 7     | 5     | 0   |
| 80  | 12                                      | 10    | 8     | 6     | 4     | 0   |
| 90  | 11                                      | 9     | 7     | 5     | 3     | 0   |
| 100 | 10                                      | 8     | 6     | 4     | 2     | 0   |
| 110 | 9                                       | 7     | 5     | 3     | 1     | 0   |
| 120 | 8                                       | 6     | 4     | 2     | 0     | 0   |
| 130 | 7                                       | 5     | 3     | 1     | 0     | 0   |
| 140 | 6                                       | 4     | 2     | 0     | 0     | 0   |
| 150 | 5                                       | 3     | 1     | 0     | 0     | 0   |
| 160 | 4                                       | 2     | 0     | 0     | 0     | 0   |
| 170 | 3                                       | 1     | 0     | 0     | 0     | 0   |
| 180 | 2                                       | 0     | 0     | 0     | 0     | 0   |
| 190 | 1                                       | 0     | 0     | 0     | 0     | 0   |
| 200 | 0                                       | 0     | 0     | 0     | 0     | 0   |

Table 3.1: Marginal Abatement Cost (MAC) per technology type.  $T_1, \dots, T_5$  denote the conventional technologies, while  $a$  denotes the advanced abatement technology.

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<sup>4</sup>Alternatively, from reasons that are explained bellow, our analysis includes the case of a flat MD curve (MD=55).

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| Firm type         | $T_1$ | $T_2$ | $T_3$ | $T_4$ | $T_5$ |
|-------------------|-------|-------|-------|-------|-------|
| Number of firms   | 4     | 3     | 4     | 3     | 4     |
| Permits allocated | 8     | 7     | 6     | 5     | 4     |

Table 3.2: Firm type (according to the initial technologies), number of firms per type, and permits allocated to each firm (in the treatments with grandfathering.)

Since we have conducted both single and multi-period treatments, we define a *run* as the phase consisting of one period in the single-period treatments, and of four successive periods (i.e., periods 1-4, 5-8, 9-12) in the multi-period treatments. In all treatments, once a firm has decided to invest in the new technology, it is assigned the new technology for the remaining periods of the run.<sup>5</sup> Table 3.3 presents the experimental design.

| Treatment | $L^*$ | Allocation mechanism | Auction design | Investment sustainability | Permits validity | Periods | Runs |
|-----------|-------|----------------------|----------------|---------------------------|------------------|---------|------|
| SAAC      | 110   | A                    | AC             | each period               | each period      | 6       | -    |
| SGAC      | 108   | GR                   | AC             | each period               | each period      | 4       | -    |
| SGDA      | 108   | GR                   | DA             | each period               | each period      | 6       | -    |
| MAAC      | 110   | A                    | AC             | each run                  | each period      | 12      | 3    |
| MGDA      | 108   | GR                   | DA             | each run                  | each period      | 12      | 3    |

Every treatment includes 2 sessions with 18 participants  
Common to all treatments:  $\Pi^0=1200$ ,  $j^*=7$ ,  $n=18$ ,  $k=5$

Table 3.3: The experimental design, a total of 5 treatments: three single-period treatments and two multi-period treatments. “A” denotes auctioning off permits, “GR” denotes grandfathering, “AC” denotes ascending clock auction, “DA” denotes double auction. run=period in the single-period treatments but not in the multi-period treatments.

For our parameters, the optimal allocation is characterized as follows: All firms assigned the technologies  $T_1$  and  $T_2$  should invest, while the others should not, as is illustrated by Figure 3.1. The optimal number of permits to be issued is  $L = 110$ , and the optimal marginal damage is equal to 55.

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<sup>5</sup>However, in each period during a run, a firm can invest in the advanced technology if it did not invest before.

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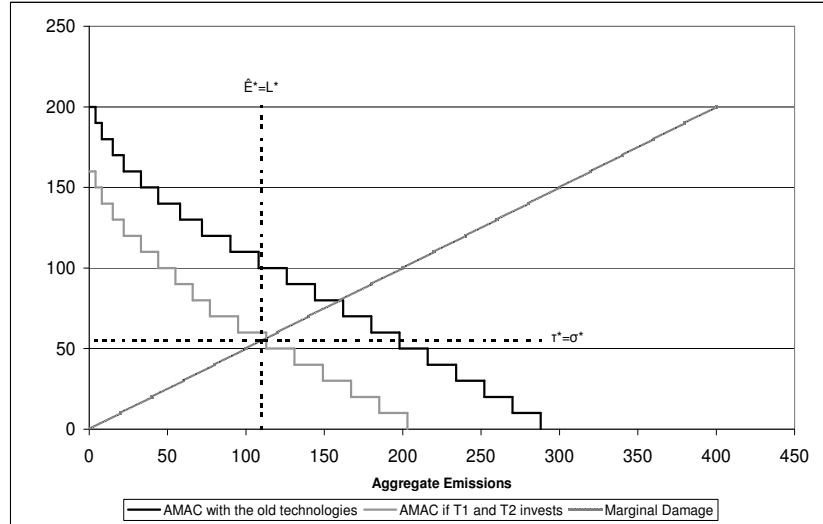


Figure 3.1: Socially optimal instrument level, tax and emission permits

To ensure that subjects understand the economic situation, only students with at least a Bachelor’s degree in Economics were recruited to participate in the experiment. Second, every experimental session starts with a tax treatment and is then followed by a permit treatment. This means that instead of trading permits, emissions were taxed. The purpose of conducting the tax treatment before the permit treatment was to make subjects familiar with the pure investment decision without facing the uncertainty induced through the outcome on the permit market, in particular regarding permit price. Finally, we did not impose an automatic time limit on the investment decision, giving the subjects enough time to consider their decisions. When, however, some subjects did not make their decision after 15 minutes, we told them to reach a decision.

#### 3.3.1 The tax treatments

Assuming that the regulator anticipates the new technology, we set the *ex-ante* optimal tax rate equal to  $\tau = 55$ . According to the above settings, the profit of firm  $i$ , in period  $t$ , is the following:



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$$\Pi_{i,t} = \begin{cases} \Pi^0 - C^i(e_{i,t}, a) - \tau e_{i,t} & \text{if invested in period } t \text{ (or earlier),} \\ \Pi^0 - C^i(e_{i,t}, k) - \tau e_{i,t} & \text{if not invested in period } t \text{ (or earlier),} \end{cases}$$

where  $k = T_1, \dots, T_5$ . Total profit is then given by  $\Pi_i^{total} = \sum_{t=1}^T \Pi_{i,t} - F$ , if the firm invested during the run, or otherwise  $\Pi_i^{total} = \sum_{t=1}^T \Pi_{i,t}$ , where  $T = 1$  for the single-period treatment and  $T = 4$  for the multi-period treatment.

#### 3.3.2 The permit treatments

As soon as the tax treatment had been finished and after a short break, the permit treatment started. In all three permit treatments we announce that the regulator issues (auctions off or grandfathers) a number of permits equal to  $L = 110^6$ .

When **permits are auctioned off through an ascending clock auction** (in the SAAC and MAAC treatments), we set the initial price equal to 5 ECU, the firms have 40 seconds to place their demand for permits (their requested number of permits) at that price. If the aggregate permits' demand is higher than the permits' supply (110 permits), the price is increased by 10 ECU (such that the next price is 15 ECU, then 25 ECU, and so on). The auction then continues until the demanded quantity placed by the firms is smaller or equal to the permits' supply of 110. If this is the case, the auction ends and each firm obtains its demanded quantity at this last price.<sup>7</sup>

When the **grandfathering is followed by an ascending clock auction** (SGAC), the procedure is similar to the SAAC treatment, except that now for the given price, the subjects have 40 seconds to place their demand (their requested number of permits) or their supply (the number of permits they offer). If the aggregate demand is smaller or equal to the aggregate supply, the auction ends and each bidder gets his or her demanded quantity at this last price.<sup>8</sup>

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<sup>6</sup>or 108 due to allocation considerations in the treatments with grandfathering.

<sup>7</sup>If a subject does not submit her demand at the given price when the time is over, the computer program automatically submits the subject's demand from the previous price. If the subject does not submit her demand in the initial price, (5 ECU), the computer program automatically submits her maximum emission level. However, this has rarely occurred.

<sup>8</sup>If the demand is equal to the supply, then also each offerer sells her offered quantity.

### 3.3 Experimental Design and Procedure

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The profit of firm  $i$  in period  $t$ , for the treatments with ascending clock auction (SAAC, SGAC, MAAC), is the following:

$$\Pi_{i,t} = \begin{cases} \Pi^0 - C^i(e_{i,t}, a) - \sigma e_{i,t} Z_{i,t} & \text{if invested in period } t \text{ (or earlier),} \\ \Pi^0 - C^i(e_{i,t}, k) - \sigma e_{i,t} Z_{i,t} & \text{if not invested in period } t \text{ (or earlier),} \end{cases}$$

where  $k = T_1, \dots, T_5$ . Here  $Z_{i,t} = 1$  in the case of auctioning off permits, and  $Z_{i,t} \in \{1, -1\}$  in the case of grandfathering, depending on whether the firm buys ( $Z_{i,t} = 1$ ) or sells ( $Z_{i,t} = -1$ ) permits at the given period. Total profit is defined the same as in the tax treatment (section 3.3.1).

When the **grandfathering is followed by a single unit double auction** (in the SGDA, and MGDA treatments), the subjects have 3 minutes to buy and sell permits in the market. They can buy and sell permits either by submitting a bid or an offer, or by accepting a standing bid or an offer. The bids (offers) are ordered from highest to lowest (lowest to highest). If two bids (offers) are tied, the one entered first has priority. After a permit has been traded the auction continues for the next permit. The profit to firm  $i$  in period  $t$  is given by

$$\Pi_{i,t} = \begin{cases} \Pi^0 - C^i(e_{i,t}, a) - x & \text{if invested in period } t \text{ (or earlier),} \\ \Pi^0 - C^i(e_{i,t}, k) - x & \text{if not invested in period } t \text{ (or earlier),} \end{cases}$$

where  $k = T_1, \dots, T_5$ , and  $x$  is defined as  $x = \sum_{j=1}^J \sigma_{i,j,t} Z_{i,j,t}$ , where  $J$  is the number of trades,  $\sigma_{i,j,t}$  is the price subject  $i$  pays or receives in trade  $j$ , and  $Z_{i,j,t} \in \{1, -1\}$  indicates whether he or she buys ( $Z_{i,j,t} = 1$ ) or sells ( $Z_{i,j,t} = -1$ ) a permit. Net trade sum up to  $\sum_{j=1}^J Z_{i,j,t} = e_{i,t} - \hat{e}_i$  where  $\hat{e}_i$  is subject  $i$ 's initial endowment of permits. Total profit is defined the same as in the tax treatment (section 3.3.1).

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However, if the demand is smaller than the supply, a random mechanism determines who of the offerers will sell her offered quantity and who will not.

### 3.3.3 Attitude towards risk and subjects' performance

An interesting question is whether risk attitude of subjects could account for their investment and speculative behavior. For this purpose, we employ the low-payoff menu of paired lottery (Holt & Laury, 2002). This menu measures attitudes toward risk in levels indicating a risk-attitude coefficient ranging from 1 (high degree of risk-loving) to 10 (high degree of risk-aversion). A coefficient of 4 denotes risk neutrality. Appendix 3.6.1 provides a detailed description of the menu. The distribution of risk coefficients of our sample is given in Figure 3.2.

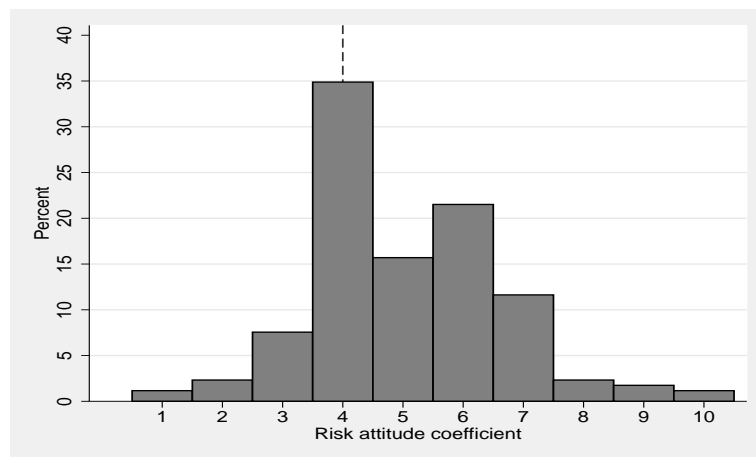


Figure 3.2: The distribution of the risk-attitude coefficients, a total of 173 subjects (average: 5.02, standard deviation: 1.58). Coefficients in the range 1-3 indicate risk loving, coefficient of 4 indicates risk neutrality, and coefficients in the range 5-10 indicate risk aversion

## 3.4 Results

This section starts by reporting the results of the tax treatment and then proceeds with the examination of the different regulation policies (SAAC, SGAC, SGDA, MAAC, MGDA). We are interested in possible deviations from (i) the optimal investment in advanced abatement technology, (ii) the efficient allocations of permits (reflected in the total abatement costs given the investment decision), and (iii) the optimal total social welfare in the economy.

### 3.4.1 The tax treatments

Since the tax treatment is basically a maximization problem, non-optimal decisions of the subjects are considered as ‘mistakes’. Consequently, we identify three types of mistakes: (i) A non-optimal abatement decision, i.e., a firm abates more or less units than optimal under the given tax rate; (ii) non-optimal timing of investment in the multi-period treatments, i.e., a firm invests after the first period of a run; (iii) non-optimal investment decision, i.e., either a firm that should not invest, does invest, or a firm that should invest, does not invest. Table 3.4 presents the percentage of mistakes in the first and last runs of the treatment.

|  | % of investment mistakes | % of timing mistakes | % of abatement mistakes |
|--|--------------------------|----------------------|-------------------------|
| The first run                                      | 19.12                    | –                    | 26.87                   |
| The last run                                       | 7.85                     | –                    | 8.79                    |
| (a) The single-period tax treatment (126 subjects) |                          |                      |                         |
|  | % of investment mistakes | % of timing mistakes | % of abatement mistakes |
| The first run                                      | 25.00                    | 5.55                 | 29.16                   |
| The last run                                       | 8.33                     | 4.16                 | 8.33                    |
| (b) The multi-period tax treatment (72 subjects)   |                          |                      |                         |

Table 3.4: Percentage of mistakes in the first run compared with the last run of the tax treatments. In the multi-period treatment we refer to abatement mistakes in the first and last periods of the corresponding runs.

Table 3.4 illustrates that the percentage of mistakes is substantially lower in the last run compared with the first run, indicating that at the end of the treatment the subjects understand the economic situation in a much better way. At the end of the treatment, less than 10% of the decisions taken by the subjects are considered as mistakes. Note that timing mistakes were almost never observed, even in the first run.

**Result 1:** *At the end of the tax treatment subjects significantly improve their understanding of the economic situation. Less than 10% of their decisions are considered as mistakes.*

### 3.4.2 Investment decisions in permit markets

Figure 3.3 presents the distribution of investment depending on the initial technology assigned to the firms in the different treatments.<sup>9</sup>

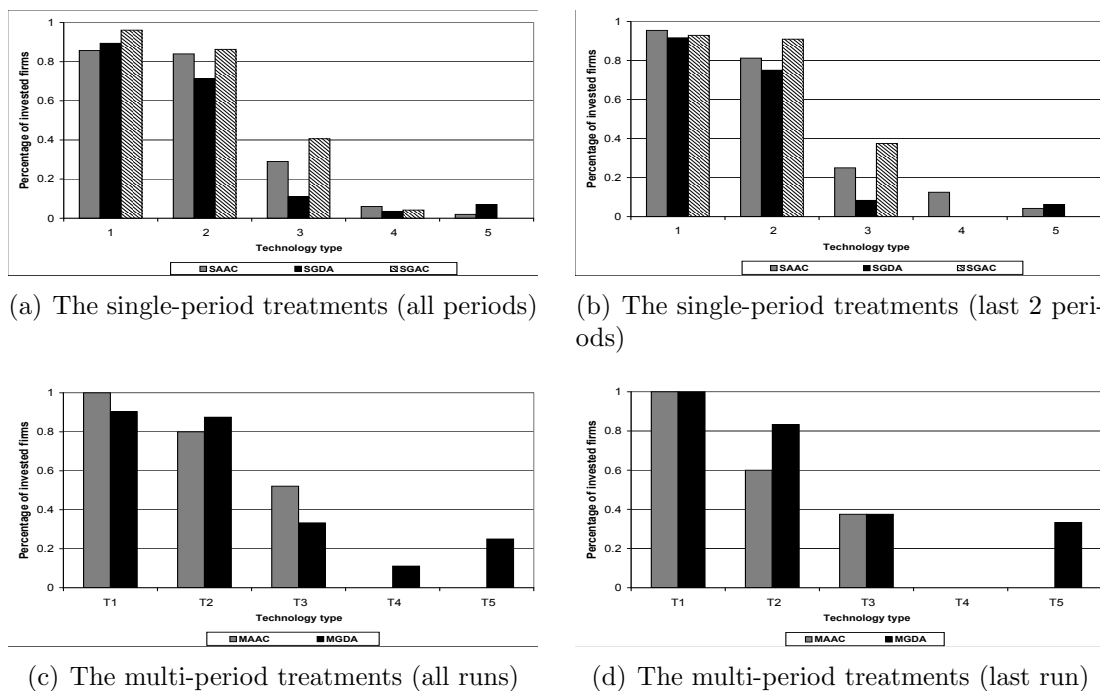


Figure 3.3: Percentage of firms investing in the new technology per conventional technology type

Using a Flinger and Policello robust rank order test (F-P test) to compare between the single-period SAAC and SGAC treatments, we cannot reject the null hypothesis that the initial allocation of permits does not affect the investment pattern, at the 10% s.l.

**Result 2a:** *The initial allocation of permits (auctioning vs. grandfathering) does not affect the pattern of investment.*

This is a remarkable result because economic theory predicts final permit allocation to be invariant to the initial allocation when the number of firms is

<sup>9</sup>This figure present the ‘clean’ data, after omitting subjects who made more than a single mistake in the last two periods of the tax treatment - on average 2 subjects per treatment.

sufficiently large (see [Kennedy & Laplante, 2000](#); [Montero, 2002a,b](#); [Requate & Unhold, 2001, 2003](#)).

Comparing the single-period SGAC and SGDA treatments by using an F-P test, we cannot reject the null hypothesis that the auction design does not affect investment decision at the 10% s.l.

**Result 2b:** *The auction design (an ascending clock auction vs. a single unit double auction) does not affect the pattern of investment.*

This result is notable since it justifies abstraction from the particular auction design as is done in many theoretical papers and textbooks on competitive permit trading (for instance [Baumol & Oates, 1988](#); [Kolstad, 2000](#); [Tietenberg, 2006](#)).

Finally, comparing the single-period SAAC and SGDA treatments to their corresponding multi-period treatments using an F-P test, we cannot reject the null hypothesis of no significant difference between the treatments at the 10% level.

**Result 2c:** *The single-period treatments and the multi-period treatments yield similar patterns of investment.*

In line with result 2c we also observe that only 10% and 3% of the firms who invested during the MAAC and the MGDA treatments, respectively, invested in a different period than the first period of each run. This means that, by and large, firms do not observe the market before investing in the multi-period treatments, but rather decide whether to invest or not at the beginning of each run as in the single-period treatments.

### 3.4.3 Characteristics of the permit markets

In this section we investigate the different permit markets with respect to prices and volumes. We proceed by analyzing the relationships between prices, the risk-attitude coefficients, the initial technology assigned, investments, and speculative behavior.

Table 3.5 compares the observed average prices<sup>10</sup> and volumes with their expected values depending on the observed pattern of investment. Recall that market prices and volumes of trade reflect the size of demand and supply of permits in the market (which depend on the investments).

| Treatment | Observed         |                  | Expected                       |                 |
|-----------|------------------|------------------|--------------------------------|-----------------|
|           | Price            | Volume           | Price                          | Volume          |
| SAAC      | 55.00<br>(11.83) | 103.81<br>(5.32) | 45.45 – 53.63<br>(8.20 – 9.24) | 110<br>(–)      |
| SGAC      | 60.00<br>(10.69) | 32.87<br>(5.66)  | 49.16 – 59.16<br>(8.86)        | 35<br>(3.42)    |
| SGDA      | 64.84<br>(10.01) | 44.16<br>(10.56) | 49.16 – 59.16<br>(7.93)        | 35.41<br>(3.77) |
| MAAC      | 53.33<br>(6.37)  | 102.39<br>(5.00) | 36.66 – 46.66<br>(5.16)        | 110<br>(–)      |
| MGDA      | 58.21<br>(11.82) | 41.25<br>(3.77)  | 43.33 – 53.33<br>(5.16)        | 35.66<br>(2.42) |

Table 3.5: Comparison of observed average prices and trade volumes of permits with the expected average prices and trade volumes given the observed pattern of investment (standard deviations are given in brackets)

Table 3.5 shows that the observed prices are higher than the expected prices in all treatments. Moreover, we find too little trading in the treatments using the ascending clock auction and excessive trading in the treatments using the double auction. A possible explanation for over-trading in the treatments with double auction is that these treatments allow for speculative trading (defined as buying and selling permits by the same firm in a given period). Table 3.6 presents the net trading in the DA treatments, defined as the absolute value of permits at the end of the period minus initial permits.

<sup>10</sup>The price range is a result of the stepwise aggregate marginal abatement cost function which we are using. For example, when we allocate 110 (or 108) permits and only firms of type  $T_1$  and  $T_2$  invest in the advanced technology, we expect the permit price to range between 50 and 60.

| Treatment | Observed volume |                  | Expected volume<br>(net trading) |
|-----------|-----------------|------------------|----------------------------------|
|           | Net trading     | Total trading    |                                  |
| SGDA      | 30.83<br>(7.95) | 44.16<br>(10.56) | 35.41<br>(3.77)                  |
| MGDA      | 33.04<br>(3.16) | 41.25<br>(3.77)  | 35.66<br>(2.42)                  |

Table 3.6: Comparison of the observed average net trading volume and the total average trading volume of permits with the expected average volume given the observed pattern of investment in the DA treatments (standard deviations are given in brackets)

Table 3.6 illustrates that there is also too little-(net) trading in the DA treatments compared with the expected trading volume according to the theoretical prediction.

### 3.4.3.1 Factors influencing investment

To better understand what factors are influencing the investment behavior in the different treatments, we estimate a Probit model (using the pooled data across firms and over time) for the single-period treatments.<sup>11</sup> The explanatory variables are the following: investment in the previous period (a dummy variable obtaining the value of 1 when the firm invested in the previous period), the initial technology assigned (a discrete variable ranging between 1 for the least efficient technology and 5 for the most efficient technology), the average price in the previous period, and the risk-attitude coefficient (see [Holt & Laury, 2002](#)) ranging between 1 and 10. The estimation results are given in Table 3.7.

<sup>11</sup>We also estimated a random-effect panel Probit model to account for individual heterogeneity, but a likelihood ratio test indicates that the pooled model is preferred.



### 3.4 Results

| Treatment                    | SAAC               | SGAC               | SGDA               |
|------------------------------|--------------------|--------------------|--------------------|
| Investment ( $t - 1$ )       | 1.17***<br>(0.25)  | 0.89**<br>(0.42)   | 1.00***<br>(0.26)  |
| Technology                   | -0.48***<br>(0.08) | -1.23***<br>(0.23) | -0.76***<br>(0.11) |
| Risk-attitude coef.          | 0.01<br>(0.06)     | -0.19<br>(0.16)    | 0.19*<br>(0.11)    |
| Average price ( $t - 1$ )    | 0.02***<br>(0.00)  | 0.02<br>(0.01)     | 0.01<br>(0.01)     |
| Cons                         | -0.82<br>(0.66)    | 2.86***<br>(1.56)  | -0.46<br>(0.1.28)  |
| LR test (K-1)                | 77.97***           | 95.34***           | 115.46***          |
| McFadden's Pseudo $R^2$      | 0.33               | 0.67               | 0.49               |
| McFadden's Pseudo adj. $R^2$ | 0.29               | 0.60               | 0.44               |

\*, \*\*, \*\*\* denote significance at the 10%, 5%, and 1% levels, respectively

Table 3.7: Probit estimations of the different single-period treatments (Std. Err. are given in brackets). The dependent variable: Investment at period  $t$ .

We find that the initial technology and investment in the previous period are significantly correlated with investment in all treatments. The result that the initial technology affects investment stems from the asymmetric effect of investment according to the firms' initial technologies (i.e. the least efficient firms gain more by investing). The result that investment in the previous period is correlated with current period investment may indicate state dependence (Heckman, 1981). This means that, for the single-period treatments, once a subject has invested (has not invested) in a certain period, there is a higher probability that he will invest (not invest) in the following period, *ceteris paribus*. Prices in previous periods significantly affect investment only in the SAAC treatment.<sup>12</sup> This result is puzzling since the expected price of permits is supposed to affect the firm's consideration in whether or not to adopt the advanced technology. Therefore, we expected that the previous period price would have a significant effect on investment in all treatments. Finally, the risk-attitude coefficient is significantly correlated with investment only in SGDA treatment. We can summarize our findings as follows:

<sup>12</sup>For the DA treatment, we also estimated other models including the average selling price per subject and the average buying price per subject (including only the transactions that were made by the specific subject). However, the corresponding coefficients are not statistically significant.

**Result 3a:** A dirtier initial technology and investment in the previous period are positively correlated with investment in all treatments. A tendency towards risk aversion is positively correlated with investment in the SGDA treatment (the risk attitude coefficient was not significant in the other treatments). A high permit price in the previous period is positively correlated with investment in the SAAC treatment (the previous period permit price coefficient was not significant in the other treatments).

### 3.4.3.2 Factors influencing speculative behavior

Lets us define a *speculator* as a trader who sells and buys permits within the same period. In order to reveal the factors influencing speculative behavior we estimate the Probit model presented in Table 3.8.<sup>13</sup>

| Variable                     | Coef. (Std. Err.) |
|------------------------------|-------------------|
| Speculation ( $t - 1$ )      | 1.00***<br>(0.24) |
| Technology                   | -0.12<br>(0.011)  |
| Risk-attitude coef.          | -0.16*<br>(0.08)  |
| Investment ( $t$ )           | -0.44<br>(0.34)   |
| Average price ( $t - 1$ )    | 0.02*<br>(0.01)   |
| Cons                         | -1.24<br>(1.12)   |
| LR test (K-1)                | 35.24***          |
| McFadden's Pseudo $R^2$      | 0.19              |
| McFadden's Pseudo adj. $R^2$ | 0.12              |

\*, \*\*, \*\*\* denote significance at the 10%, 5%, and 1% levels, respectively

Table 3.8: Probit estimation of the SGDA treatment. The dependent variable: Speculation at period  $t$ .

Table 3.8 indicates that speculation in the previous period, average price

<sup>13</sup>As in section 3.4.3.1, We also estimated a random-effect panel Probit model to account for individual heterogeneity, but a likelihood ratio test indicates that the pooled model is preferred.

in the previous period, and a low risk-attitude coefficient (a tendency towards risk-loving) are positively and significantly correlated with the current period speculation. These findings are quite intuitive since the incentives to speculate depend on the average buying and selling price, moreover, we expect speculators to have a tendency towards risk loving. Finally, we also observe state dependence (Heckman, 1981) as in the case of investment behavior.

**Result 3b:** *Speculative behavior in the previous period, a high average price in the previous period, and a tendency towards risk-loving are positively correlated with speculative behavior in the current period.*

### 3.4.4 Efficiency in allocation of permits

Besides optimal investment, an additional measure of efficiency in permits market is the efficiency in allocation of permits. This is measured by the total abatement cost (TAC) given the observed pattern of investment. In other words, we test whether firms (subjects) make efficient use of the auction to minimize the TAC of the industry. Table 3.9 presents the average observed TAC with the average efficient TAC given the observed pattern of investment. The efficiency ratio (*observed TAC/efficient TAC*) is a measure of efficient allocation of permits. The lower the ratio, the higher is the efficiency of the market. When permits are allocated efficiently (and the marginal abatement costs are balanced between all firms)<sup>14</sup> the efficiency ratio is equal to 1.

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<sup>14</sup>Since the number of permits in our experiment is an integer, it can happen that the marginal abatement cost is different between the firms (by at most one unit).

| Treatment | Observed TAC         | Efficient TAC       | Efficiency ratio |
|-----------|----------------------|---------------------|------------------|
| SAAC      | 3679.09<br>(1426.94) | 2782.72<br>(963.68) | 1.32<br>(0.26)   |
| SGAC      | 3957.50<br>(1117.63) | 3294.16<br>(976.97) | 1.30<br>(0.11)   |
| SGDA      | 3328.75<br>(1084.25) | 2577.50<br>(955.77) | 1.20<br>(0.09)   |
| MAAC      | 2800.41<br>(799.82)  | 2038.33<br>(333.07) | 1.36<br>(0.26)   |
| MGDA      | 3094.58<br>(674.28)  | 2643.33<br>(505.29) | 1.17<br>(0.09)   |

Table 3.9: Average observed and efficient TAC (given the observed pattern of investment) in the different treatments (standard deviations are given in brackets). The efficiency ratio is defined as *observed TAC/efficient TAC*.

Using a Kruskal-Wallis test to compare between the series of efficiency ratios, we do not find a significant difference between the three single-period treatments at the 10% level. Using an F-P test to compare between each pair of treatments, we find that the SGDA outperforms the SGAC treatment at the 10% s.l. We, however, do not find differences between the SGDA and the SAAC treatments at the 10% s.l. Using an F-P test, comparing between the two the multi-period treatments, we find that the MGDA treatment outperforms the MAAC treatment at the 10% level (all the results reported are of two-sided test).

**Result 4:** *Regarding efficiency in allocation of permits, the SGDA treatment outperforms the SGAC treatment, and the MGDA treatment outperforms the MAAC.*

### 3.4.5 Total social welfare in permit markets

Finally, we evaluate the regulation policies through comparing the total social welfare (TSW) defined as the sum of the unconditional profits minus the investment and abatement costs across firms, minus the total damage to the society from pollution. We consider two cases: an increasing marginal damage (MD) schedule ( $MD = E/2$ ), and a constant marginal damage schedule with  $MD = 55$ . A flat

MD schedule is chosen following Tol's (2005) estimation of Carbon Dioxide emissions.<sup>15</sup> Table 3.10 presents the average efficiency ratios (defined as: *observed TSW/efficient TSW*) for each treatment. Note that, in this case, in contrast to the efficiency measure on the total abatement costs, the higher the efficiency ratio the higher the efficiency in the market.

| Treatment | Efficiency ratio<br>(flat MD function) | Efficiency ratio<br>(increasing MD function) |
|-----------|--|--|
| SAAC      | 0.89<br>(0.07)                         | 0.92<br>(0.05)                               |
| SGAC      | 0.89<br>(0.03)                         | 0.91<br>(0.02)                               |
| SGDA      | 0.87<br>(0.06)                         | 0.91<br>(0.04)                               |
| MAAC      | 0.93<br>(0.05)                         | 0.94<br>(0.03)                               |
| MGDA      | 0.89<br>(0.03)                         | 0.94<br>(0.01)                               |

Table 3.10: Mean (and standard deviations) of the 'efficiency ratio' (defined as, *observed TSW/efficient TSW*) series of the Total Social Welfare (TSW), calculated assuming a flat marginal damage (MD=55) schedule or assuming an increasing marginal damage schedule (MD=E/2), in the different treatments.

Regarding a flat MD schedule, comparing the series of efficiency ratios between the different single-period treatments, using a Kruskal-Wallis test and an F-P test for each pair of treatments, we do not find differences between treatments at the 10% s.l. However, using an F-P test, comparing between the multi-period treatments, we find that the MAAC treatment outperforms the MGDA treatment at the 10% s.l. Applying the same tests for the TSW with increasing MD schedule we do not find a difference between the single-period and between the multi-period treatments, respectively, at the 10% s.l.

**Result 5:** *Overall, the different treatments do not perform differently with respect to total welfare losses.*

<sup>15</sup>Tol (2005) estimates a rather flat MD schedule (under a 4-5% social rate of discount, he estimates the MD as \$16/tC, not exceeding \$62/tC with a probability of 95%).

## 3.5 Concluding Remarks

This study aims at testing, by means of a laboratory experiment, whether both methods of initial allocation of permits and the choice of auction design affect the incentives to invest in advanced abatement technology in tradable permit markets with small asymmetric firms. Altogether, we conducted a total of five treatments, varying the way the permits are initially allocated (costly vs. free), the auction design (ascending clock auction vs. single unit double auction), and the relevant time horizon within the treatments (single-period vs. multi-period).

Regarding investment in advanced technology, we do not find significant differences between the treatments, a result in line with many theoretical predictions. We also observed, as in [Gangadharan \*et al.\* \(2005\)](#), that at least some firms of each initial technology invest in the new technology (even firms with the cleanest technology). In particular, we find under-investment by the inefficient firms and over-investment by efficient firms.

Regarding the total social welfare, we do not find significant differences between the treatments. However, regarding optimal allocation of permits we find weak evidence that the single unit double auction outperforms the ascending clock auction. Thus, we deliver a further argument in favor of the double auction trading institution. The result that grandfathering is not inferior to auctioning in any of the evaluation criteria<sup>16</sup>, is particularly interesting in light of the tendency of economists to prefer auctioning on grandfathering (see, for instance, [Cramton & Kerr, 2002](#)).

In summary, this paper's novelty comes from testing the effect of initial allocation of permits on adoption of advanced technology. Moreover, it also tests the effect of two alternative auction designs on adoption of advanced technology. Our results confirm that in a market consisting of a sufficiently large number of firms, the initial allocation of permits does not affect the investment behavior. Our findings also indicate that, by and large, both auction designs perform similarly. Thus, we support the abstraction from the auction design when evaluating the effect of emission permits as a policy instrument. Finally, although laboratory experiments were often used to investigate the static efficiency of alternative en-

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<sup>16</sup>Our analysis does not include political economy considerations such as the costs of lobbying when grandfathering is implemented, or that grandfathering may set up an entry barrier, etc.

### 3.5 Concluding Remarks

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vironmental policy instruments under various conditions, there was not much use of experiments to investigate the dynamic efficiency of adopting (or developing) advanced technologies. Thus, experimental economics should still clarify issues relating to the incentives to adopt or develop advanced technologies.

### Acknowledgements

We are grateful to Johanna Reichenbach and all assistants who supported us in conducting the experiment. We are also grateful for helpful comments from participants in the ESA international meeting in Washington DC.

## 3.6 Appendix to Chapter 3

### 3.6.1 Holt and Laury's (2002) menu of paired lottery

Holt and Laury's (2002) low payoff menu of paired lottery (see Figure 3.4) requires subjects to choose between two lotteries: A and B. The 'solid' lottery A includes a probability to win a high payoff of €2 and a (complementary) probability to win a low payoff of €1.6.<sup>17</sup> Similarly, the 'riskier' lottery B includes a probability to win a high payoff of €3.85 and a (complementary) probability to win a low payoff of €0.1. The probabilities to win the high (and low) payoffs are the same for both lotteries A and B. The probability to win the high payoff increases gradually during the lottery choice menu in increments of 10%, such that from a probability of 10% to win the high payoff and a probability of 90% to win the low payoff in the first lottery-choice it reaches a probability of 100% to win the high payoff and 0% to win the low payoff in the last choice of the menu. As the probability to win the high payoff in both lotteries increases, subjects are expected to switch from A to B. For instance, a risk neutral subject, who chooses the lottery according to the highest expected value, will choose 4 times A before switching to B. Consequently, from the pattern of choices observed, a risk-attitude coefficient which corresponds to the number of consecutive choices of lottery A before switching to lottery B, is computed.

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<sup>17</sup>In the original study by Holt & Laury (2002) the payoffs are in US\$.



### 3.6 Appendix to Chapter 3

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Name \_\_\_\_\_ Date \_\_\_\_\_

| Number | Option A                      | Option B                      | Your Decision<br>(A or B) |
|--------|-------------------------------|-------------------------------|---------------------------|
| 1      | 1/10 of €2.00, 9/10 of €1.60  | 1/10 of €3.85, 9/10 of €0.10  |                           |
| 2      | 2/10 of €2.00, 8/10 of €1.60  | 2/10 of € 3.85, 8/10 of €0.10 |                           |
| 3      | 3/10 of €2.00, 7/10 of €1.60  | 3/10 of €3.85, 7/10 of €0.10  |                           |
| 4      | 4/10 of €2.00, 6/10 of €1.60  | 4/10 of € 3.85, 6/10 of €0.10 |                           |
| 5      | 5/10 of €2.00, 5/10 of €1.60  | 5/10 of €3.85, 5/10 of €0.10  |                           |
| 6      | 6/10 of €2.00, 4/10 of €1.60  | 6/10 of €3.85, 4/10 of €0.10  |                           |
| 7      | 7/10 of €2.00, 3/10 of €1.60  | 7/10 of €3.85, 3/10 of €0.10  |                           |
| 8      | 8/10 of €2.00, 2/10 of €1.60  | 8/10 of €3.85, 2/10 of €0.10  |                           |
| 9      | 9/10 of €2.00, 1/10 of €1.60  | 9/10 of €3.85, 1/10 of €0.10  |                           |
| 10     | 10/10 of €2.00, 0/10 of €1.60 | 10/10 of €3.85, 0/10 of €0.10 |                           |

Figure 3.4: Holt and Laury's (2002) menu of paired lottery

### 3.6.2 Translated instructions (the multi-period treatments)

#### General instructions

Welcome. You are taking part in an economic experiment on decision making. The experiment consists of two parts. Both parts last over several rounds and in each part you can earn a reasonable amount of money. During the experiment your payoff is measured in Experimental Currency Units (ECU). At the end of the experiment it will be converted into € at an exchange rate of 160:1, i.e. 160 ECU = 1€ and it will be paid to you privately in cash.

At the beginning of the experiment each one of you will be assigned a number. From then on, you and the other participants will be identified by this number, please keep it until you receive your payment. In addition, There are two empty sheets of paper that you can use during the experiment. You will also find a calculator on the computer screen for your use. No communication is allowed with the other participants during the session. If you have any question please raise your hand and we will answer your question privately.

#### The economic background and the rules of the experiment:

Consider an industry consisting of 18 firms. Imagine you are the manager of one of these firms and that each of the other participants manages one of the remaining 17 firms. Each firm produces goods with a certain technology and gets a **profit of 1200 ECU** for such production activity. Production, however, results in the emission of pollution to the environment and therefore it is subject to potential regulation by the government.

In this industry firms use different production technologies. Each of you will be randomly assigned one particular technology. In total 5 different technologies are available at the moment. The technologies differ in the maximum emissions level per unit produced and therefore in the cost of reducing emissions.

**Your technology**

Table 3.11 describes an example of a **firm's technology**. Assume that Table 3.11 presents your firm's technology. Note that if you do not take any abatement measures, you will emit 20 units of pollution to the environment.

| Your Emissions | Units Abated | MARGINAL Abatement Cost | TOTAL Abatement Cost |
|----------------|--------------|-------------------------|----------------------|
| 20             | 0            | 0                       | 0                    |
| 19             | 1            | 10                      | 10                   |
| 18             | 2            | 20                      | 30                   |
| 17             | 3            | 30                      | 60                   |
| 16             | 4            | 40                      | 100                  |
| 15             | 5            | 50                      | 150                  |
| 14             | 6            | 60                      | 210                  |
| 13             | 7            | 70                      | 280                  |
| 12             | 8            | 80                      | 360                  |
| 11             | 9            | 90                      | 450                  |
| 10             | 10           | 100                     | 550                  |
| 9              | 11           | 110                     | 660                  |
| 8              | 12           | 120                     | 780                  |
| 7              | 13           | 130                     | 910                  |
| 6              | 14           | 140                     | 1050                 |
| 5              | 15           | 150                     | 1200                 |
| 4              | 16           | 160                     | 1360                 |
| 3              | 17           | 170                     | 1530                 |
| 2              | 18           | 180                     | 1710                 |
| 1              | 19           | 190                     | 1900                 |
| 0              | 20           | 200                     | 2100                 |

Table 3.11: **CONVENTIONAL TECHNOLOGY.**

The 1st column in the table present your emission level, and the 2nd column present the corresponding emission units you abated. In this example the maximal amount of emission is 20 units (**Note that in the experiment you can get each of the other technologies with maximum emission levels of 18 ,16 ,14 12**).<sup>18</sup>

<sup>18</sup>The distribution of technologies in the industry are as follows: 4 firms each, with maximum

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The 3rd column present the Marginal abatement costs. This column answers the question: how much it costs to reduce one unit of emission, reducing the first unit of emission costs 10 ECU, reducing the second unit of emission unit costs 20 ECU and so on. The more units you want to reduce the higher the cost of abating one additional unit.

The 4th column present the total abatement cost. It is the sum of the marginal cost until your reduced unit. For example, if you want to reduce 4 units of emission (that is, instead of emitting 20 units (your maximum emission level), you emit 16 units) it will cost you  $10 + 20 + 30 + 40=100$  ECU.

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emission levels of 20, 16 and 12. 3 firms each, with maximum emission level of 18 and 14.

**New technology**

In addition, there is a new technology available to all firms in this industry. At a certain point, you and the other participants will be given the possibility to decide whether you want to pay the investment cost and adopt the new technology or continue using the conventional one. The use of the new technology reduces your maximum emissions per unit of production (as well as the associated abatement costs). The properties of the new technology are displayed in Table 3.12. However, if you want to adopt the new technology this will cost you a fixed payment that will be announced later on.

| Your Emissions | Units Abated | MARGINAL Abatement Cost | TOTAL Abatement Cost |
|----------------|--------------|-------------------------|----------------------|
| 7              | 0            | 0                       | 0                    |
| 6              | 1            | 10                      | 10                   |
| 5              | 2            | 20                      | 30                   |
| 4              | 3            | 30                      | 60                   |
| 3              | 4            | 40                      | 100                  |
| 2              | 5            | 50                      | 150                  |
| 1              | 6            | 60                      | 210                  |
| 0              | 7            | 70                      | 280                  |

Table 3.12: **NEW TECHNOLOGY.**

**PART I: Regulation by emission tax**

In this part of the experiment the government decides to use a tax system in order to control the emissions. This part consists of two *runs* (a *run* consists of 4 periods). Before that, a *trial run* will help you to understand the mechanism and become familiar with the tax system. At the beginning of each *run* you and the other participants will be randomly assigned a technology. In addition, a certain tax per unit of emissions will be announced. This means that you have to pay a fixed tax for every unit of emission. In each period you and the managers of the other 17 firms, must decide simultaneously and independently in the following sequence:

- First decision: You must decide **whether you want to invest and produce using the new technology, or to use the conventional one.** If you want to adopt the new technology, you must pay a fixed amount of **2000 ECU.** **Once the investment decision is done, you produce using the new technology during the periods until the end of the run.**
- Second decision: You must **decide on your emission level,** or equivalently, how many units you want to abate, starting from the maximal emission level. Note that you will pay an abatement cost depending on the units reduced and a tax proportional to your emission level.

**Notice that, once you decide to invest in the new technology (the first decision), you will produce using the new technology in the remaining periods of the run and you will have only have to decide about the emissions (the second decision) in the remaining periods of the run.**

Your profit at the end of each period is determined as follows:

- If you use the **conventional technology,** your profit in the given period is:  
$$1200 - (\text{total abatement cost as in Table 3.11}) - \text{tax} \cdot (\text{your emissions})$$
- If you invest in the **new technology,** your profit ***in the period of investment*** is:

$$1200 - (\text{your total abatement cost as in Table 3.12}) - \text{tax} \cdot (\text{your emissions}) \\ - 2000$$

- If you invested in the **new technology** in a **previous period**, your profit in the current period (you already paid for the new technology) is:

$$1200 - (\text{your total abatement cost as in Table 3.12}) - \text{tax} \cdot (\text{your emissions})$$

Your profit at the end of this part is the accumulated profit obtained in one of the (two) runs that will be randomly chosen at the end of the experiment.

To improve your understanding please look at the following examples:

**Example 1:** *Assume a tax of 30 ECU per emission unit. You decide to use the conventional technology and then your maximum emissions are 20 units. You decide then to abate 6 units, that is, emit 14 units. Then your profit **at the given period** is:*

$$1200 - 210 - 30 \cdot 14 = 570$$

*If you do not invest in the whole run (4 periods) and you abate 6 units in each period, **your total profit at the end of the run** is:*

$$570 \cdot 4 = 2280$$

*Assume that the tax is still 30 ECU and you do not invest in the new technology. However, now you abate 3 units in the first period (that is, you emit 17 units). Then your profit **at the given period** is:*

$$1200 - 60 - 30 \cdot 17 = 630$$

*If you do not invest in the whole run (4 periods) and you abate 3 units in each period, **your total profit at the end of the run** is:*

$$630 \cdot 4 = 2520$$

**Example 2:** *Assume a tax of 43 ECU per emission unit. You decide to invest in the new technology (then your maximum emission is 7 units) **in the first period** and to abate 4 units (that is, emit 3 units). If you choose to abate 4 units in the remaining 3 periods, your profit **at the end of the run** is:*

$$4 \cdot [1200 - (100) - 43 \cdot 3] - 2000 = 1884$$

**Example 3:** Assume a tax of 43 ECU per emission unit. You decide to use the **conventional technology at the first period** and to abate 4 units, your Profit at the end of the **first period** is:

$$1200 - (100) - 43 \cdot 16 = 412$$

At the 2nd period you decide to invest in the **new technology** and to abate 4 units, your Profit at the end of the **second period** is:

$$1200 - (100) - 43 \cdot 3 - 2000 = -1029$$

At the 3rd and the 4th periods you decide to abate 4 units, your Profit at the end of the **each of these periods** would be:

$$1200 - (100) - 43 \cdot 3 = 971$$

Then your total Profit **at the end of the run** is:

$$412 - 1029 + 971 \cdot 2 = 1325$$

or, equivalently:

$$412 + 971 \cdot 3 - 2000 = 1325$$

Notice that in the experiment you may get a different technology than in Table 3.11. Your technology will appear on the computer screen. In addition, you will find in front of you a paper describing all 5 conventional technologies together with the new technology.



**PART II: Regulation by emission permits -  
MAAC<sup>19</sup>**

The government decides to use an emission permits system to control the emissions. The permit system works as follows: you must hold one permit for every unit of emissions emitted by your firm. *For example, if the maximum emission level of your technology is 20 units and you hold 10 permits, you are allowed to emit up to 10 units and you must abate the remaining 10 units paying the corresponding abatement cost.*

The target set by the government is that the total emissions should not exceed 110 units. Therefore, at the beginning of each period the government issues 110 permits with a 1-period lifetime. This means that you can use the permits only for 1 period. The price of the permits will be determined using **an auction**, where you have the chance to buy permits from the government.

This part of the experiment lasts 3 *runs*. Before that, two *trial periods* will help you to understand the auction mechanism and become familiar with the emission permit's auction procedure. Each *run* consists of 4 periods. At the beginning of each *run* you and the other participants will be randomly assigned a technology. In each period you and the other 17 participants, must decide simultaneously in the following sequence:

- First decision: You must decide **whether you want to invest and produce using the new technology, or to use the conventional one.** If you want to adopt the new technology you should pay a fixed amount of **2000 ECU.** **Once the investment decision is done, you produce using the new technology during the periods until the end of the run.**
- Second decision: Emission permits auction: **You will have the opportunity to purchase emission permits.** Recall that for every unit of emission emitted by your firm you should purchase an emission permit or otherwise pay the corresponding abatement cost. However, while the abatement cost is known beforehand, **the price of the permits will be determined using an auction.**

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<sup>19</sup>'MAAC' did not appear in the original instructions.

Notice that, once you decide to invest in the new technology (the first decision), you will produce using the new technology in the remaining periods of the run and you will only have to decide about the emissions (the second decision) in the remaining periods of the run.

Your payoff at the end of each period is determined as follows:

- If you use the **conventional technology**, your profit at the given period is:

$$1200 - (\text{total abatement cost [Table 3.11]} - \text{permit price} \cdot (\text{number of permits purchased})).$$

- If you invest in the **new technology**, your profit **at the period of investment** is:

$$1200 - (\text{total abatement cost [Table 3.12]} - \text{permit price} \cdot (\text{number of permits purchased}) - 2000.$$

- If you invested in the **new technology in a previous period**, your profit at the current period (you already paid for the new technology) is:

$$1200 - (\text{total abatement cost [Table 3.12]} - \text{permit price} \cdot (\text{number of permits purchased}))$$

The auction procedure is explained on the next page.

Your profit at the end of this part is the accumulated profit obtained in one of the (three) runs that will be randomly chosen at the end of the experiment.

### The emission permits auction

Recall that the government issues every period a total of 110 emission permits to the whole industry. In each period, you can purchase emission permits in an auction.

Each auction will take place in several rounds using the following procedure:

- A permit price of 5 ECU is announced.
- You and the other participants, will be required to simultaneously introduce your permit demand, that is, the number of permits you are willing to purchase at this price. Note that you cannot purchase more certificates than you need (your maximum level of emission).
- The total demand of permits (the aggregate number of permits that the firms want to purchase) will be then computed. If the sum of the individual demands is:
  - equal or lower than 110 (the number of permits issued by the regulator): **the auction ends** and you are assigned your demanded permits paying this price per unit demanded.
  - higher than 110: The permit price will be increased by 10 ECU and **a new auction round will start**.

You have 40 seconds to introduce your permits' demand. If no demand is introduced by 40 seconds, the system will take your demand for the previous price. If you did not introduce your demand at initial price (5 ECU), the system would consider your demand equal to your maximum emission level!

To improve your understanding please look at the following examples:

**Example 1:** *Assume you decided to use the **conventional technology**. The auction stops with a price of 55 ECU per permit and you have demanded 14 permits at this price. Then your profit **at this period** is:*

$$1200 - 210 - 55 \cdot 14 = 220$$

**Example 2:** Assume you decided to use the *conventional technology*. The auction stops with a price of 55 ECU per permit and you have demanded 15 permits at this price. Then your profit **at this period** is:

$$1200 - 150 - 55 \cdot 15 = 225$$

**Example 3:** Assume you decided to *invest in this period in the new technology*. The auction stops with a price of 65 ECU per permit and you have demanded 1 permits at this price. Then your profit **at this period** is:

$$1200 - 210 - 65 \cdot 1 - 2000 = -1075$$

**Example 4:** Assume you invested in a *previous period in the new technology*. The auction stops with a price of 55 ECU per permit and you have demanded 2 permits at this price. Then your profit **at this period** is:

$$1200 - 150 - 55 \cdot 2 = 940$$

We will now play 2 trial auction periods so you can become familiar with the auction procedure. If you have any question, please raise your hand and we will assist you.

**PART II: Regulation by Emission Permits -  
MGDA<sup>20</sup>**

The government decides to use an emission permits system to control the emissions. The permit system works as follows: you must hold one permit for every unit of emission emitted by your firm. *For example, if the maximum emission level of your technology is 20 units and you hold 10 permits, you are allowed to emit up to 10 units and you must abate the remaining 10 units paying the corresponding abatement cost.*

The target set by the government is that the total emissions should not exceed 108 units. Therefore, at the beginning of each period the government issues 108 permits with a 1-period lifetime. This means that you can use the permits only for 1 period. Every period you will get an initial amount of permits (depending on the technology that was assigned to you) and you can sell to or buy permits from the other firms in the market using **an auction**.

This part of the experiment lasts 3 *runs*. Before that, two trial periods will help you understand the mechanism and become familiar with the emission permit's auction procedure. Each *run* consists of 4 periods. At the beginning of each *run* you and the other participants will be randomly assigned a technology. In each period you and the other 17 firms, must decide simultaneously in the following sequence:

- First decision: You must decide **whether you want to invest and produce using the new technology, or to use the conventional one**. If you want to adopt the new technology you should pay a fixed amount of **2000 ECU**. **Once the investment decision is done, you produce using the new technology during the periods until the end of the run.**
- Second decision: Emission permits auction: **You will have the opportunity to buy and/or sell emission permits**. Recall that for every unit of emission emitted by your firm you should purchase an emission permit or pay the corresponding abatement cost. However, while the abatement cost is known beforehand, **the price of the permits will be determined**

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<sup>20</sup>'MGDA' did not appear in the original instructions.

using an auction.

Notice that, once you decide to invest in the new technology (the first decision), you will produce using the new technology in the remaining periods of the run and you will have only have to decide about the emissions (the second decision) in the remaining periods of the run.

Your payoff at the end of each period is determined as follows:

- If you use the **conventional technology**, your profit at the given period is:

$$1200 - (\text{total abatement cost [Table 3.11]}) + \text{auction profit.}$$

- If you invest in the **new technology**, your profit **at the period of investment** is:

$$1200 - (\text{total abatement cost [Table 3.12]}) + \text{auction profit} - 2000.$$

- If you invested in the **new technology in a previous period**, your profit at the current period (you already paid for the new technology) is:

$$1200 - (\text{total abatement cost [Table 3.12]}) + \text{auction profit}$$

**Auction Profit** = Your total earnings in ECU from selling permits - Your total expenditure in ECU from buying permits (For instance, if you sell one permit in 60 ECU and one permit in 110 ECU then your total auction profit is:  $60 + 110 = 170$  ECU)

The auction procedure is explained on the next page.

Your profit at the end of this part is the accumulated profit obtained in one of the (three) runs that will be randomly chosen at the end of the experiment.

### The emission permits auction

Recall that the government issues every period a total of 108 emission permits to the whole industry. In each period, you will be assigned an initial amount of permits (depending on your technology). During **a period of 3 minutes** you, and the other participants, are free to sell and/or buy emission permits in the market.

**How can I buy 1 emission permit?** If you want to buy an emission permit you have two options:

- Submit a bid by entering at which price you are willing to buy 1 emission permit. Each auction round is for one permit, when that permit is bought you can buy one more permit. Note that if you did not buy the last permit, your bid is still pending for the next round (the next unit auctioned).
- Accept the lowest offer (the computer will choose automatically the lowest offer).

**How can I sell 1 emission permit?** If you want to sell an emission permit you have two options:

- Submit an offer by entering at which price you are willing to sell 1 emission permit. Note that you can only sell the amount of permits you own. Each auction round is for one permit, when that permit is sold out you can sell one more permit. Note that if you did not sell the last permit, your offer is still pending for the next round (the next unit auctioned).
- Accept the highest bid (the computer will choose automatically the highest bid).

During these 3 minutes you are free to buy and sell as many permits as you want. Recall that once the market closes, you should abate those emission units that exceed the number of emission permits that you hold at the end of the auction.

To improve your understanding please look at the following examples:

**Example 1:** Assume you decided to use the **conventional technology** (you got an initial allocation of 8 permits) You bought one unit at the price of 65, one unit at the price of 75 and 5 units at the price of 55. Then your profit **at this period** is:

$$1200 - 415 - 150 = 635$$

**Example 2:** Assume you decided to **invest in this period in the new technology** (you got an initial allocation of 8 permits). You soled one unit at the price of 65, one unit at the price of 75 and 3 units at the price of 55. Then your profit **at this period** is:

$$1200 + 305 - 100 - 2000 = -595$$

**Example 3:** Assume you invested in a **previous period** in the **new technology** (you got an initial allocation of 8 permits). You soled one unit at the price of 65, one unit at the price of 75 and 3 units at the price of 55. Then your profit **at this period** is:

$$1200 + 305 - 100 = 1405$$

We will now play 2 trial auction periods so you can become familiar with the auction procedure. If you have any question, please raise your hand and we will assist you.



### 3.6.3 Screens

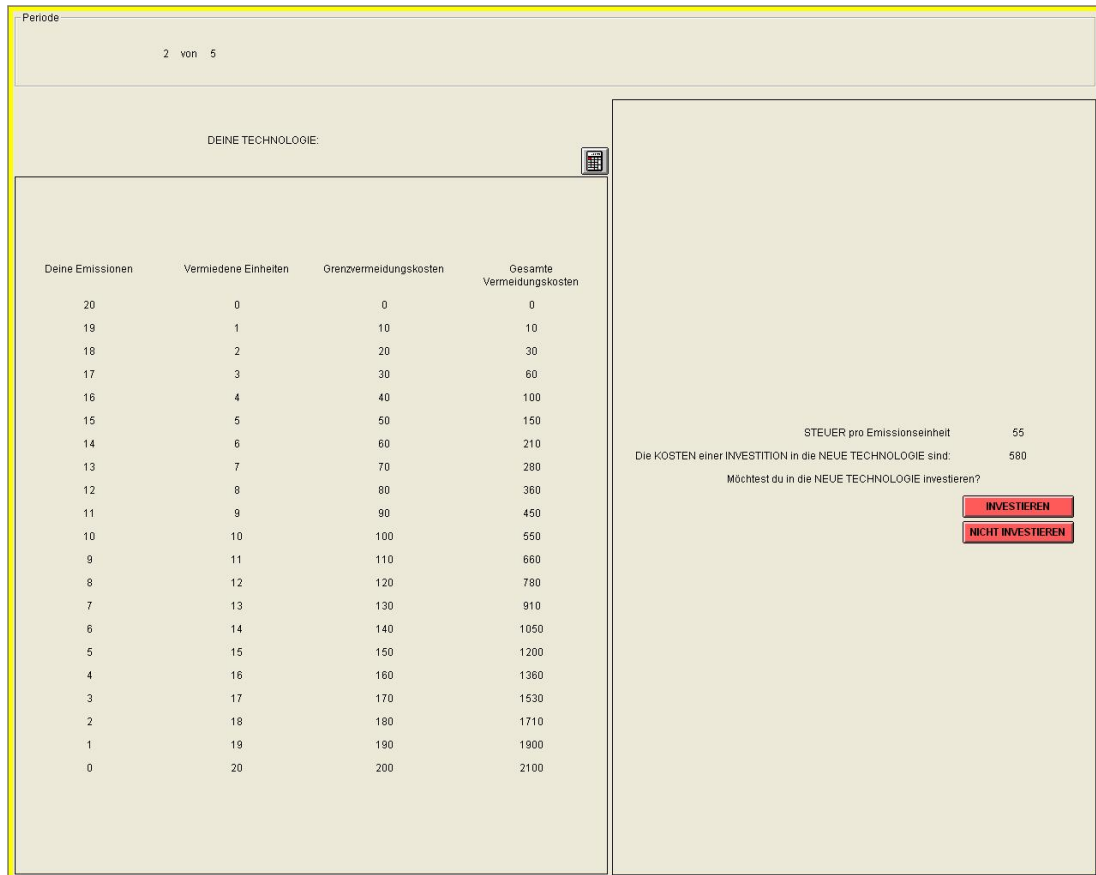


Figure 3.5: The single-period tax treatment: The ‘investment screen’ in each period.

Periode  
2 von 5

DEINE TECHNOLOGIE:

Du produzierst weiterhin mit deiner KONVENTIONELLEN TECHNOLOGIE.

| Deine Emissionen | Vermiedene Einheiten | Grenzvermeidungskosten | Gesamte Vermeidungskosten |
|------------------|----------------------|------------------------|---------------------------|
| 20               | 0                    | 0                      | 0                         |
| 19               | 1                    | 10                     | 10                        |
| 18               | 2                    | 20                     | 30                        |
| 17               | 3                    | 30                     | 60                        |
| 16               | 4                    | 40                     | 100                       |
| 15               | 5                    | 50                     | 150                       |
| 14               | 6                    | 60                     | 210                       |
| 13               | 7                    | 70                     | 280                       |
| 12               | 8                    | 80                     | 360                       |
| 11               | 9                    | 90                     | 450                       |
| 10               | 10                   | 100                    | 550                       |
| 9                | 11                   | 110                    | 660                       |
| 8                | 12                   | 120                    | 780                       |
| 7                | 13                   | 130                    | 910                       |
| 6                | 14                   | 140                    | 1050                      |
| 5                | 15                   | 150                    | 1200                      |
| 4                | 16                   | 160                    | 1360                      |
| 3                | 17                   | 170                    | 1530                      |
| 2                | 18                   | 180                    | 1710                      |
| 1                | 19                   | 190                    | 1900                      |
| 0                | 20                   | 200                    | 2100                      |

STEUER pro Emissionseinheit 55

Wie viele Emissionseinheiten möchtest du vermeiden? (VERMIEDENE EINHEITEN)

OK

Figure 3.6: The single-period tax treatment: The ‘abatement screen’ in each period.

Periode

2 von 5

**PRODUKTIONSGEWINN** 1200  
 DEINE EMISSIONEN 15  
**GESAMTE STEUERZAHLUNG** 825  
 VERMIEDENE EINHEITEN 5  
**GESAMTE VERMEIDUNGSKOSTEN** 150  
**DEIN GEWINN IN DIESER PERIODE** 225

OK

| Periode | Maximale Emissionen | Steuer | Deine Emissionen | Gesamte Steuerzahlung | Vermiedene Einheiten | Gesamte Vermeidungskosten | Gewinn |
|---------|---------------------|--------|------------------|-----------------------|----------------------|---------------------------|--------|
| 1       | 7                   | 25     | 5                | 125                   | 2                    | 30                        | 465    |
| 2       | 20                  | 55     | 15               | 825                   | 5                    | 150                       | 225    |

Figure 3.7: The single-period tax treatment: The ‘results screen’ after each period.

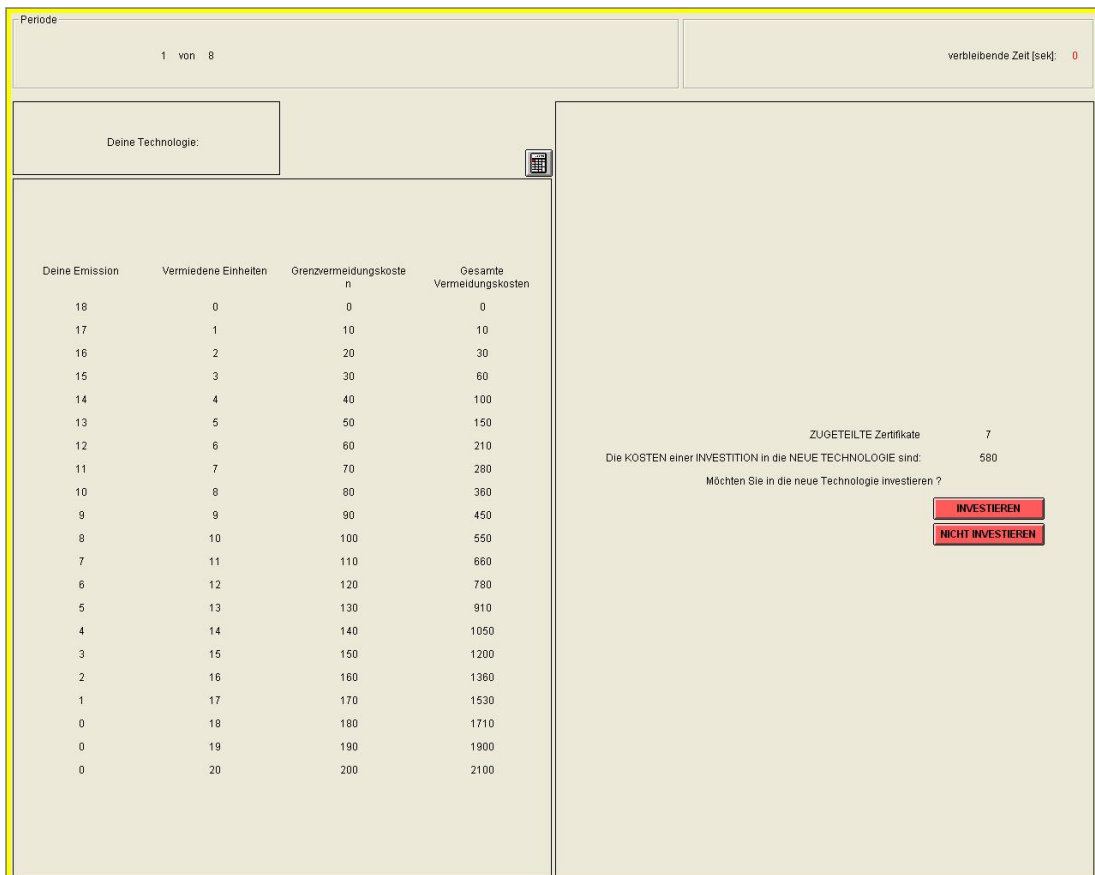


Figure 3.8: The SGDA treatment: The ‘investment screen’ in each period.

### 3.6 Appendix to Chapter 3

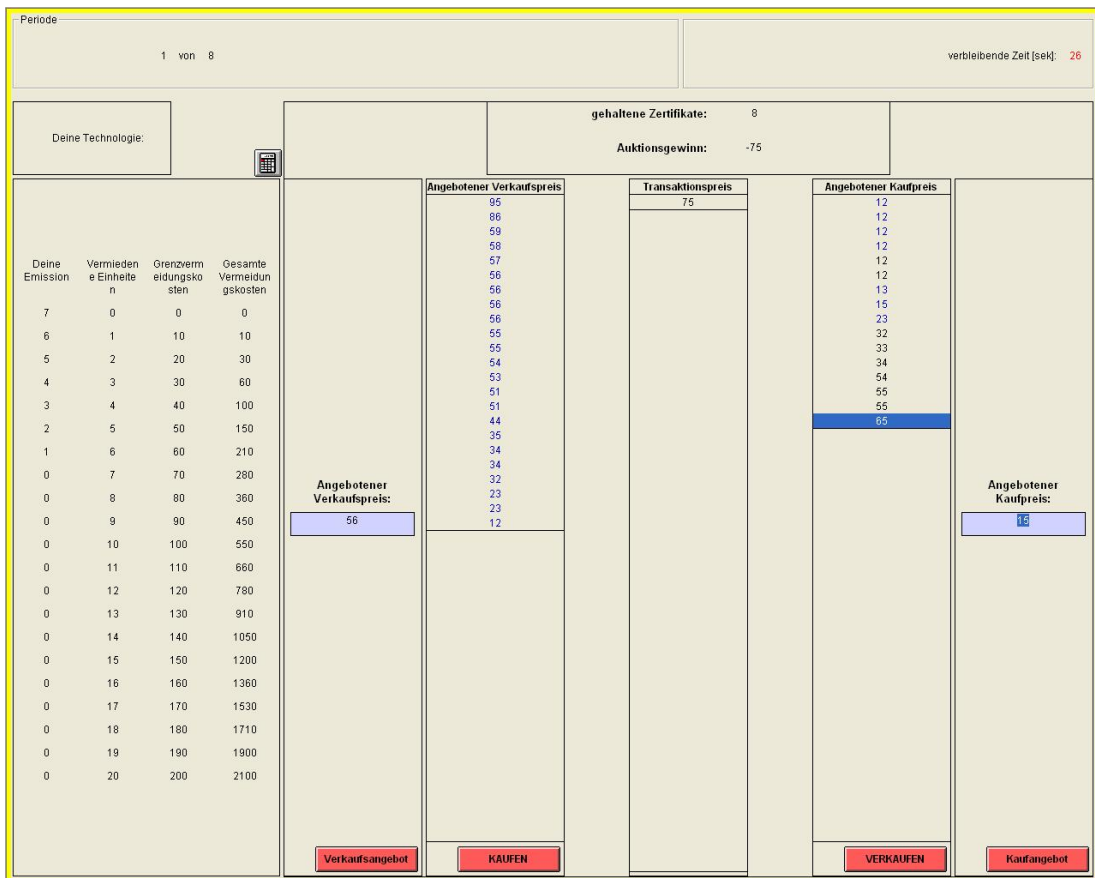


Figure 3.9: The SGDA treatment: The ‘auction screen’ in each period.

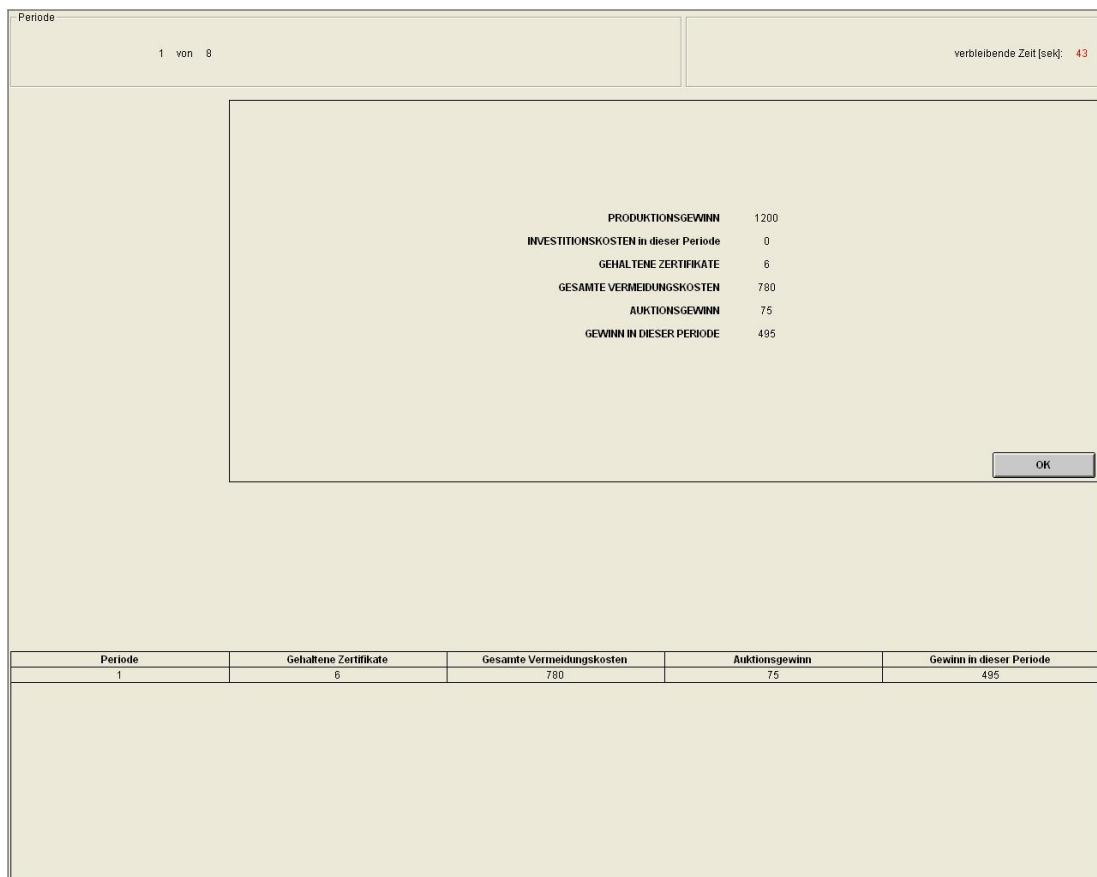


Figure 3.10: The SGDA treatment: The ‘results screen’ after each period.

### 3.6 Appendix to Chapter 3

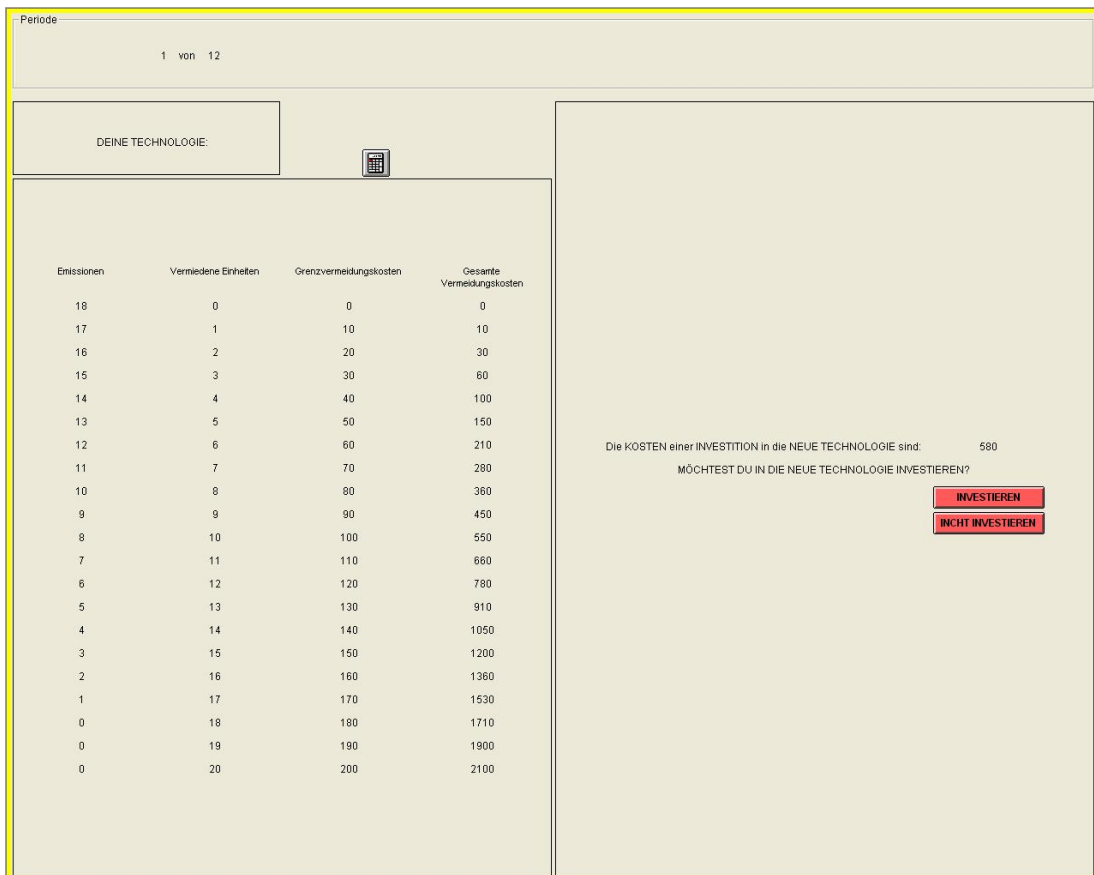


Figure 3.11: The SAAC treatment: The ‘investment screen’ in each period.

### 3.6 Appendix to Chapter 3

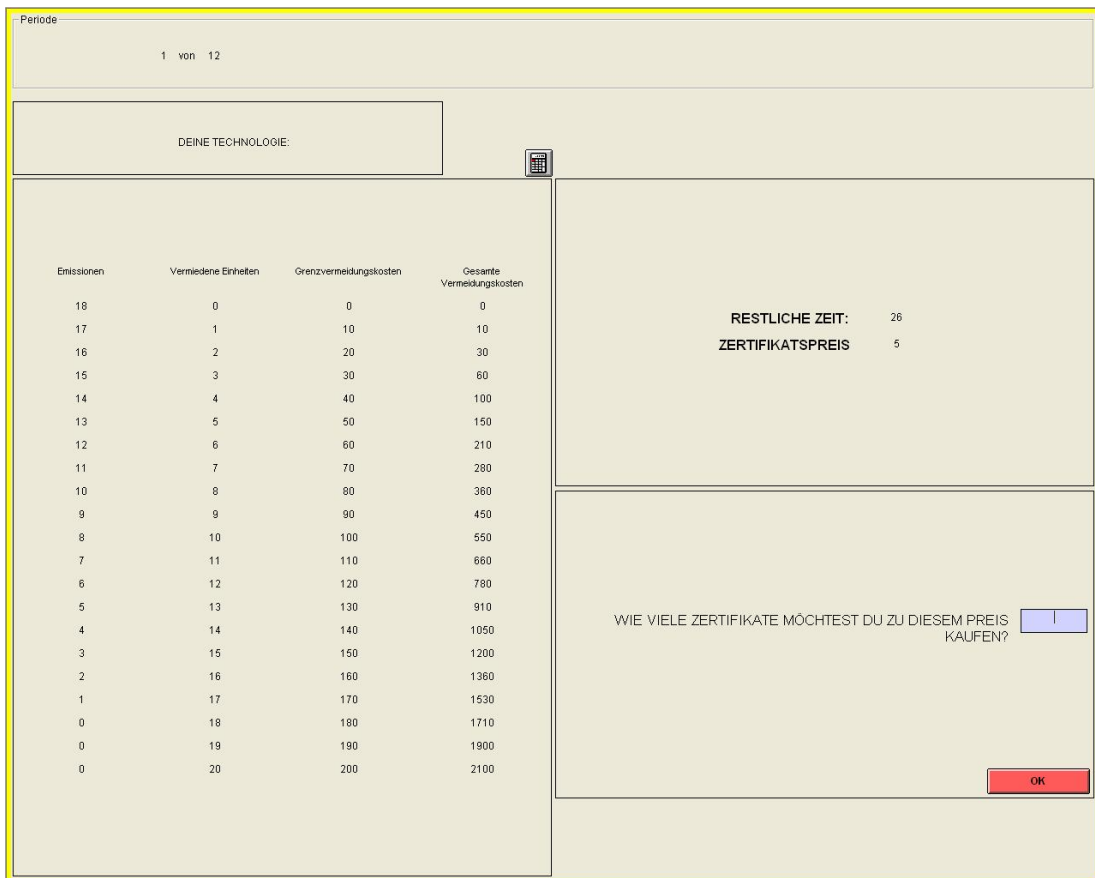


Figure 3.12: The SAAC treatment: The ‘auction screen’ in each period.



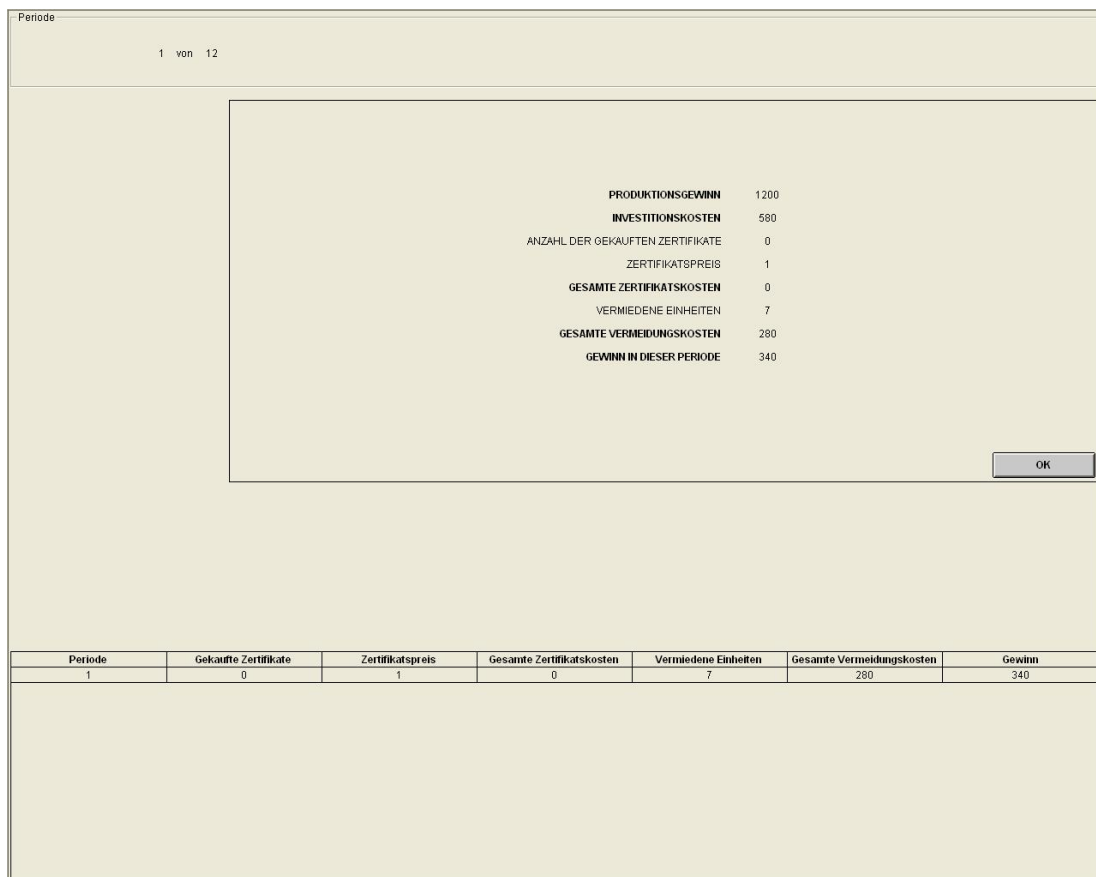


Figure 3.13: The SAAC treatment: The ‘results screen’ after each period.

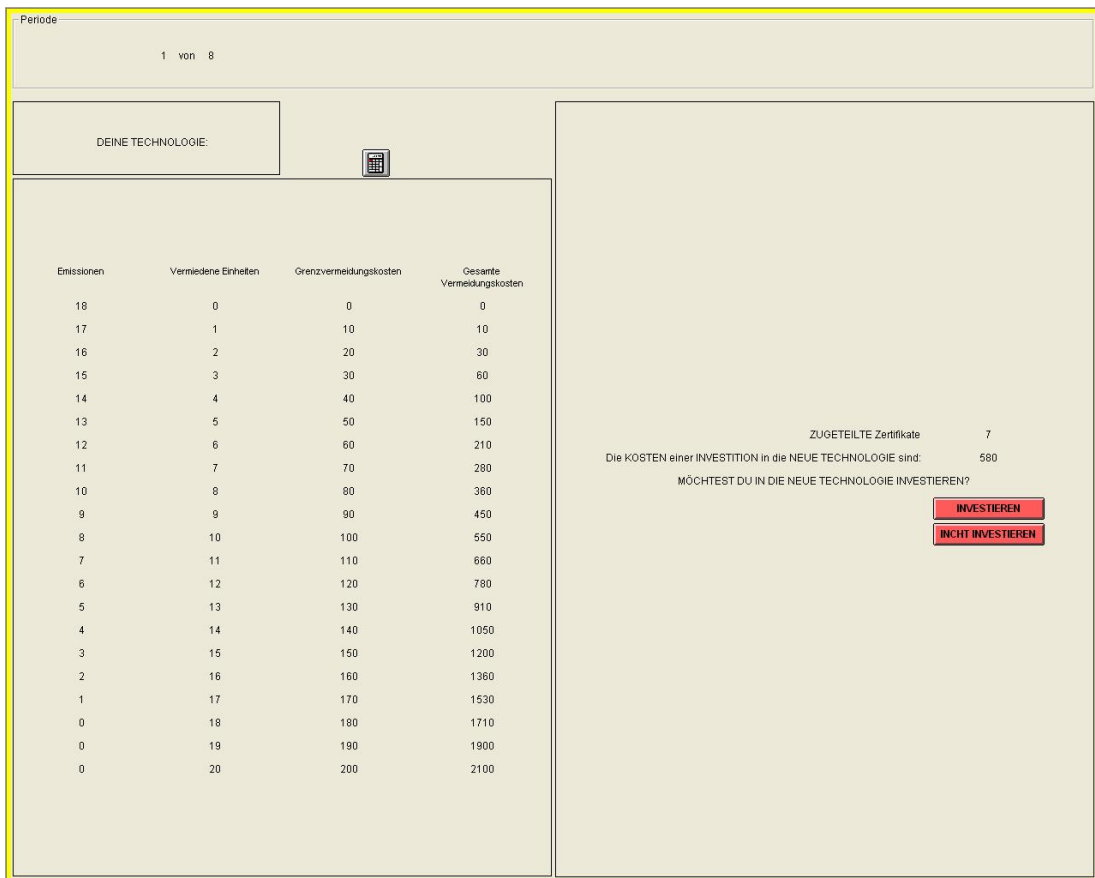


Figure 3.14: The SGAC treatment: The ‘investment screen’ in each period.

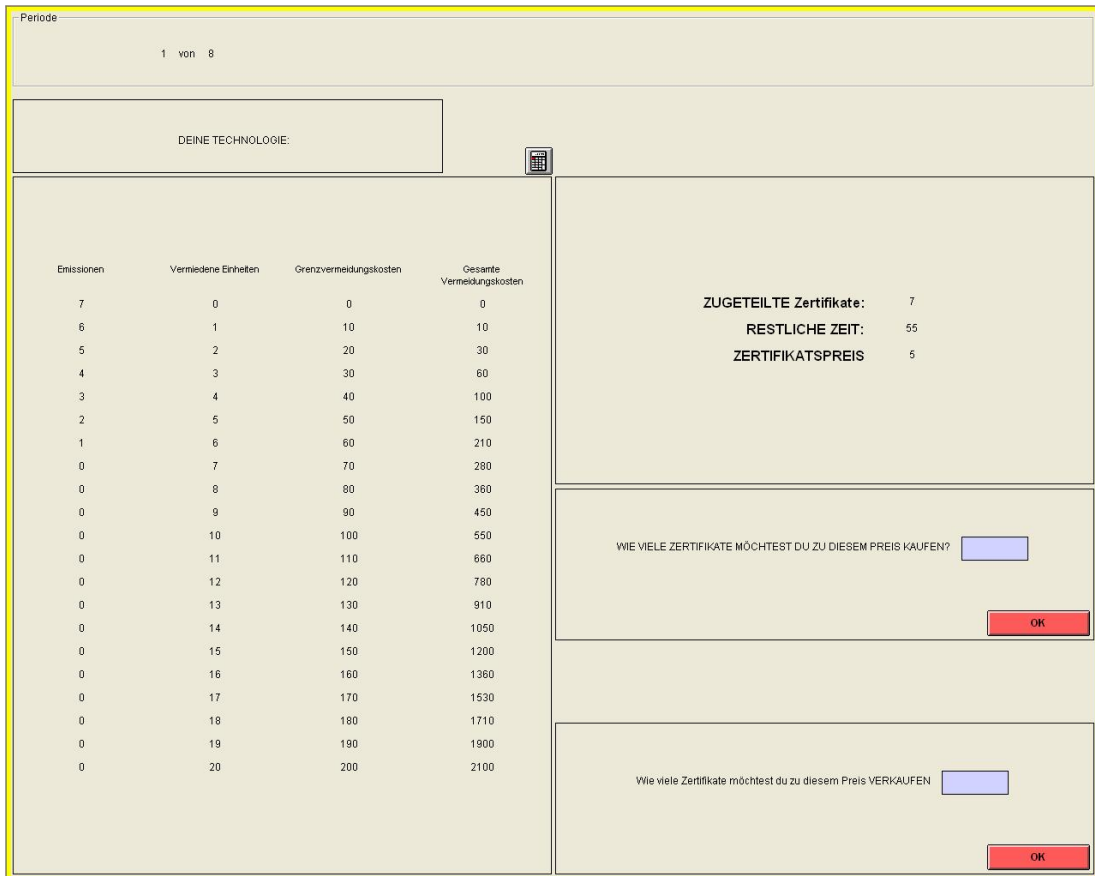


Figure 3.15: The SGAC treatment: The ‘auction screen’ in each period.

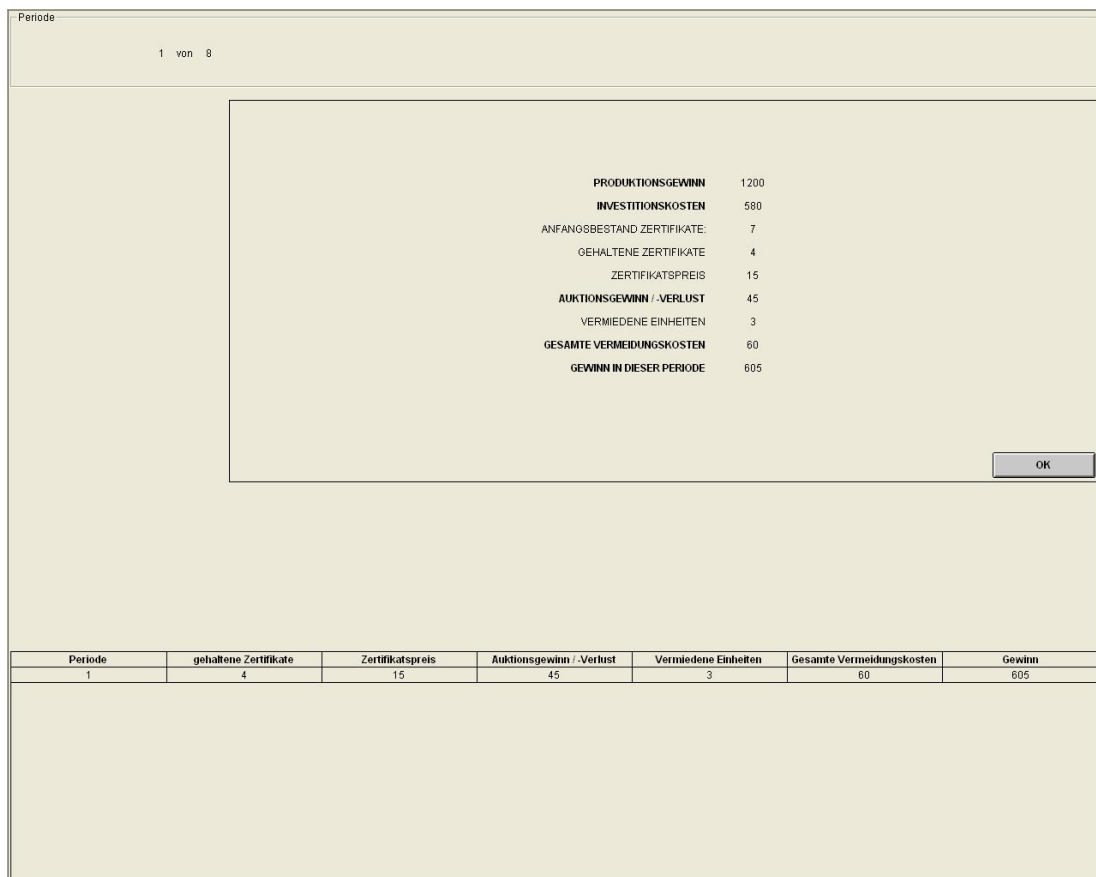


Figure 3.16: The SGAC treatment: The ‘results screen’ after each period.

## Chapter 4

# Empirical Evidence from the Kiel Market for Budget Travel by Train

### 4.1 Introduction

Since it was introduced by [Güth \*et al.\* \(1982\)](#), the ultimatum bargaining game (UG)<sup>1</sup> serves as a prominent and consistent example of a situation where the observed behavior deviates significantly from the game theoretical prediction.<sup>2</sup> There is, however, criticism whether UG indeed describes a real world phenomenon (see [Grace & Kemp, 2005](#), p.824). This motivates the search for real-world situations having an UG structure. This note investigates a unique market which shares certain features with the UG. Thus, we provide an investigation of a market which have some features of the UG in a naturally occurring environment. Moreover, the stakes in this naturally occurring situation are quite

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<sup>1</sup>The ultimatum bargaining game is a sequential game where Player A divides a pie of size  $x$  between himself and another Player B. Player B, then, decides whether to accept and receive the division made by Player A or to reject the division. If Player B rejects, both players receive zero.

<sup>2</sup>The subgame perfect equilibrium prediction for the UG is that the proposer will receive virtually all of the pie to be divided, while the responder will receive at most the smallest monetary unit in which proposals can be made. However, the results of laboratory experiments of the UG are that responders receive a much larger portion of the pie (close to half of the pie). See [Roth \(1995\)](#) for a review.

## 4.2 The Kiel Market for Budget Travel by Train

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moderate, thus, comparable to standard laboratory experiments.

The introduction of the Schleswig-Holstein ticket (S-H ticket)<sup>3</sup> by the German train company (Deutsche Bahn) created a market for budget travel by train. The S-H ticket allows up to five people to travel together for a fixed price in regional trains within two federal states in northern Germany. Due to the feature that only a single passenger who rides with the S-H ticket can continue using it after separating from the others<sup>4</sup>, it is worthwhile for some passengers (for instance, passengers who need to use the tickets later) to buy the S-H ticket and offer to take others with their ticket for a specified price.<sup>5</sup> Thus, a market for budget travel by train emerges. This market is characterized, not by spontaneous gatherings of passengers who want to share the cost of traveling, as one could expect, but rather by ‘proposers’ who offer to take ‘responders’ with their ticket. This note aims at describing and characterizing the market which we refer to as the Kiel market for budget travel by train (to Hamburg).

The note is organized as follows: The next section describes the Kiel market for budget travel by train. Section 4.3 describes the ‘ride-share community’, an alternative market for budget travel by car in Germany. In section 4.4, we investigate responders’ behavior in the Kiel market for budget travel by train by means of a natural field experiment. Finally, section 4.5 provides a short discussion.

## 4.2 The Kiel Market for Budget Travel by Train

The S-H ticket was issued by the Deutsche Bahn in June 2001. It allows up to five people to ride together for a fixed price in regional trains within the federal states of Schleswig-Holstein (including Hamburg) and Mecklenburg-Vorpommern<sup>6</sup>, be-

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<sup>3</sup>The S-H ticket is a ‘land ticket’, a ticket that allows one to travel in regional trains within a federal state (sometimes two federal states) in Germany for nearly an entire day. Another popular discount group ticket is the ‘weekend ticket’ which allows one to travel in regional trains all over Germany for a fixed amount on Saturdays and Sundays.

<sup>4</sup>One passenger has to write his name on the ticket. Therefore, that passenger can continue using the ticket after separating from the others.

<sup>5</sup>This creates an ‘arbitrage’ opportunity. A person can buy a ticket and use it to travel the entire day, taking passengers with him, and actually work as a ‘carrier’, but this rarely happened. Only  $3/133 \approx 2\%$  of the offers were made by possible professional ‘carriers’.

<sup>6</sup>Additionally, The S-H ticket allows the use of the public transportation in Hamburg.

## 4.2 The Kiel Market for Budget Travel by Train

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tween 09:00 and 03:00 during the week and 03:00 and 03:00 on weekends. The attractiveness of the tickets depends on the origin-destination distance. The ticket is especially attractive when the destination station is, on the one hand, sufficiently close to the origin station so that the potential passengers are traveling with the regional trains<sup>7</sup>, and when, on the other hand, the destination station is far enough from the origin station so that the alternative cost (the cost of buying a single ticket) is high. Two additional conditions are needed for a well-established market for budget travel by train to emerge: A sufficiently large volume of passengers from the origin station to a common destination, and a known meeting point where passengers can bargain. In other words, it is possible to form a market for budget travel by train only when the demand for budget travel is sufficiently high and where it is possible to establish a meeting point for the market to take place.

These conditions are met in Kiel, a city of 233,701 inhabitants<sup>8</sup>, which is located 97 kilometers north of Hamburg, Germany. Every route (by train) to any other major German city passes through Hamburg, and the usual fare to Hamburg is that of the regional trains. A single fare from Kiel to Hamburg (or from Hamburg to Kiel) costs €19.20, or €14.40 if one holds a train discount card (Bahncard).<sup>9</sup> Consequently, the high demand for budget travel by train to Hamburg, together with the fact that there are passengers who make a round trip, create a market for budget travel by train which is operating near the automatic ticket machines in the main train station of Kiel. There are mainly two types of agents in the market, ‘proposers’ and ‘responders’. The proposers (usually passengers who make a round trip) offer to take responders with their tickets for a specified price (a price which is independent of the number of passengers). We did not observe discrimination between responders (all passengers pay the same price).<sup>10</sup> The responders accept or reject the offer (they can also try to negotiate but that rarely occurs).

Note that this market is not fully legal. One is not allowed to change the group

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<sup>7</sup>For long distances, the Inter City (IC) or the Inter City Express (ICE) trains are mainly used.

<sup>8</sup>According to Kiel statistics report Nr. 193. (31.12.2007)

<sup>9</sup>If one is caught without a ticket in the train he has to pay a fee of €40.

<sup>10</sup>Maybe the reason for the absence of price discrimination between responders is that the payment is usually done in the train. It may be difficult for a proposer to explain a passenger why he pays more than the others.

## 4.2 The Kiel Market for Budget Travel by Train

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size or the members of the group after the first use of the ticket. Nevertheless, many of the proposers had bought the S-H ticket in Hamburg traveled with it to Kiel, and after finishing their business in Kiel, they then offer to take passengers with their ticket (back) to Hamburg. Yet, as the data clearly show, a stable market is operating, in front of the Deutsche Bahn information desk, without disturbance from the authorities.

### 4.2.1 Data

During May-June 2008 we observed the market in the main train station of Kiel on weekdays from Monday until Thursday (a total of 19 different days) for a total of four train departures to Hamburg at 16:21, 17:21, 18:21, and 19:21. We chose to observe the market in the afternoon of normal weekdays mainly due to two reasons: First, in a market with many proposers and responders (as on Fridays or weekends) it may not be feasible to document all offers. Second, we planned to enter the market as proposers, at a later stage, and offer higher prices than usually observed. This may only be possible with few proposers in the market.

On each day, we arrived at the meeting point close to the automatic ticket machines at 15:50 (half an hour before the train of 16:21 departs) and stayed there until 19:21, documenting the arrival and departure of proposers, their gender, and the prices offered. Table 4.1 presents the major characteristics of the market. Figures 4.1 and 4.2 present the distribution of prices in the market and the average number of proposers and prices according to the train departure time, respectively.



## 4.2 The Kiel Market for Budget Travel by Train

|                                     | Mean  | Std. Dev. | Min | Max |
|-------------------------------------|-------|-----------|-----|-----|
| % of male proposers                 | 68.05 | -         | -   | -   |
| % of proposers older than 40 years  | 4.13  | -         | -   | -   |
| % of cost-sharing offers            | 8.27  | -         | -   | -   |
| % of offers in the last 10 minutes  | 51.61 | -         | -   | -   |
| Proposer's Price (€)                | 5.91  | 0.76      | 3   | 10  |
| Passengers per proposer             | 3.25  | 1.17      | 0   | 4   |
| Waiting time per proposer (minutes) | 14.13 | 6.53      | 1   | 28  |

Table 4.1: Summary statistics of the Kiel market for budget travel by train. A total of 145 proposers were observed in 19 different days (Monday-Thursday) in May-June 2008, The statistics are related to the trains of 16:21, 17:21, 18:21 and 19:21 to Hamburg.

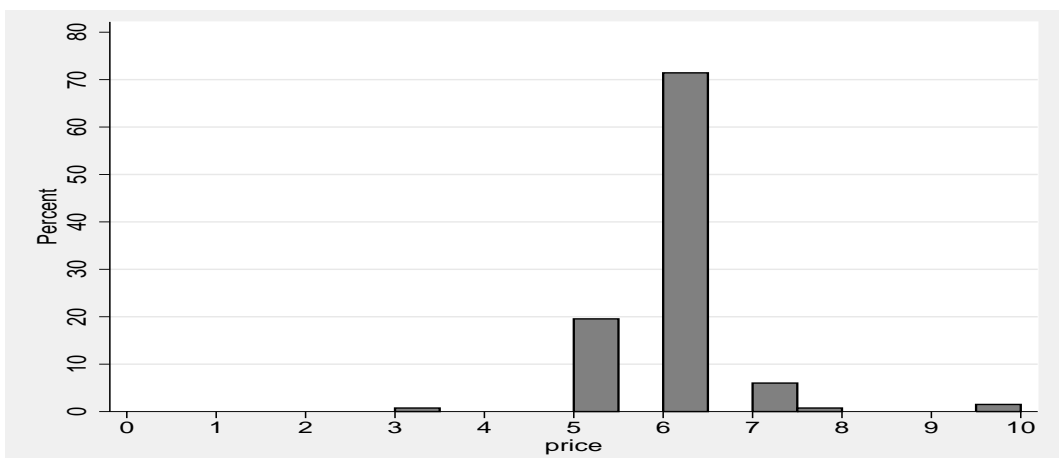


Figure 4.1: Distribution of prices in the Kiel market for budget travel by train

## 4.2 The Kiel Market for Budget Travel by Train

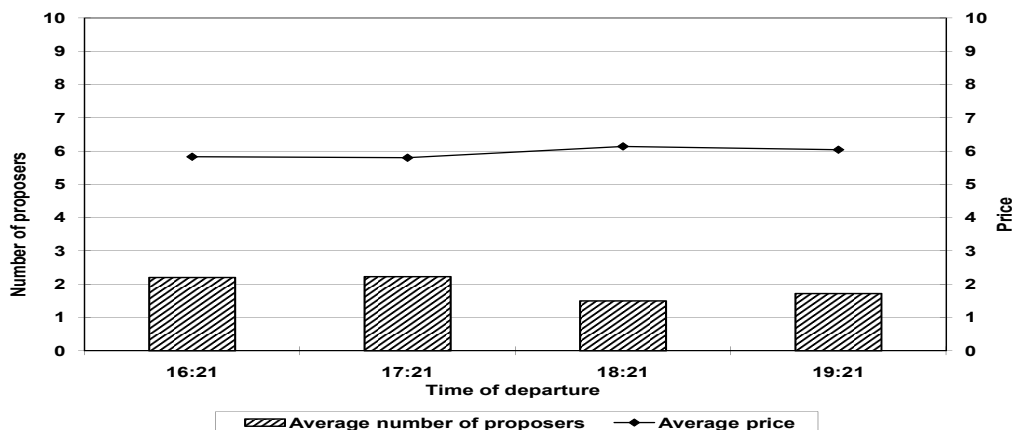


Figure 4.2: Average number of proposers, and average prices according to departure time

Table 4.1 indicates that 68% of the proposers are males, less than 5% of the proposers are (looking) older than 40 years, and 8% of the offers in the market were not strictly offers to take responders for a specified price (we denote these offers as ‘cost-sharing offers’). Each proposer waits on average 14 minutes in the market, offers to take responders for an average price of €5.91, and travels with an average number of 3.2 passengers. Two prominent features regarding the price offers are that all offers (132/133  $\approx$  99%) were of integer prices, and that most price offers (121/133  $\approx$  91%) were either €5 or €6. Another remarkable feature is that 47% of the proposers who get less than four passengers leave the market more than 10 minutes before the train departure. This means that almost half of these proposers do not act as maximizers by exhausting the time until departure. This feature is particularly puzzling, since the existence of deadline strengthens the proposers’ bargaining power. Nevertheless, we have to take into account that staying in the market until right before departure incurs the cost of getting an uncomfortable seat in the train. Table 4.2 presents the average time proposers arrive and depart from the market.

## 4.2 The Kiel Market for Budget Travel by Train

| Train departure | Average number of proposers | Average number of passengers | Average time proposers arrive | Average time proposers depart |
|-----------------|-----------------------------|------------------------------|-------------------------------|-------------------------------|
| 16:21:00        | 2.21                        | 3.5                          | 15:57:27                      | 16:11:55                      |
| 17:21:00        | 2.23                        | 2.79                         | 16:55:25                      | 17:09:49                      |
| 18:21:00        | 1.58                        | 3.44                         | 17:58:30                      | 18:14:09                      |
| 19:21:00        | 1.86                        | 3.32                         | 18:55:25                      | 19:06:49                      |

Table 4.2: Proposers arrival and departure average time

Given the prices observed in the market (together with eight observations with a price of €8 and nine observations with a price of €10 that we offered ourselves, playing the role of proposers) and the corresponding number of passengers joining the proposers at each price, we can draw the demand schedule per S-H ticket. This demand is presented in Figure 4.3.

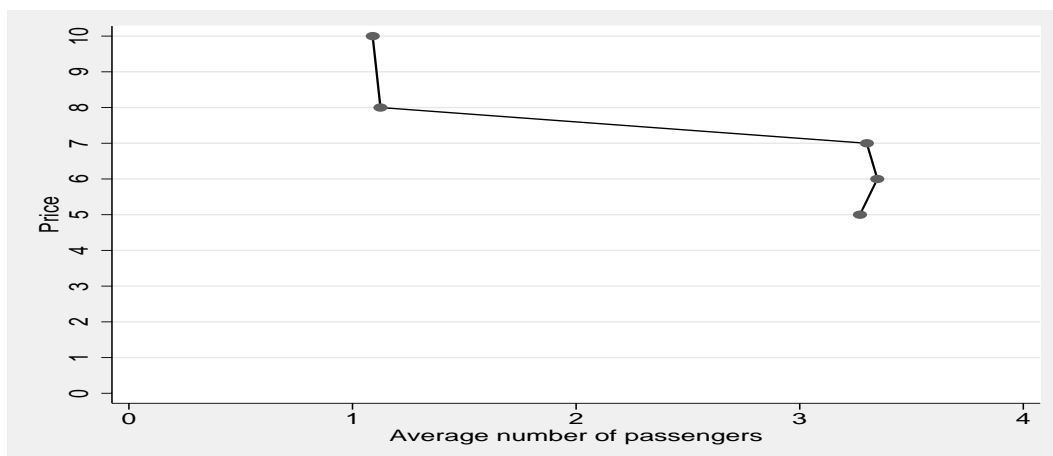


Figure 4.3: The observed demand: Average number of passengers per price offered

The positive slope of the demand schedule, in Figure 4.3, in the price range 5-6, can be attributed to the finite sample size (121 observations of prices 5 and 6).<sup>11</sup> In any case, Figure 4.3 indicates that the demand is largely inelastic at this price range. It seems that when a proposer offers a price of €7 (or lower), he can take about three to four passengers (the arc elasticity of demand between each of two nearby prices (5,6,7) is inelastic ( $|E_d| < 1$ )). However, when a proposer

<sup>11</sup>To see whether the positive slope in the price 5-6 is substantial or due to the finite sample size, we further collected eight observations, acting as proposers in the market. We have taken with us on average 3.875 passengers per time, thus, supporting the finite sample explanation.

## 4.2 The Kiel Market for Budget Travel by Train

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offers a price of €8 (or €10), he can get about one passenger (the arc elasticity of demand between the prices of 8 and 10 is also inelastic). It is obvious from Figure 4.3 that the revenue-maximizing price is €7. Formally, using a Flinger and Policello Robust Rank Order test (F-P test), we find that the revenue of proposers who charged €7 is significantly larger than the revenue of proposers who charged any other observed price (3,5,6,8 or 10).<sup>12</sup>

Finally, the prices and average waiting time according to the proposers' gender are presented in Table 4.3. The series of prices and waiting time are not significantly different from each other at the 10% level.

|                  | Price       | Waiting time |
|------------------|-------------|--------------|
| Male proposers   | 5.98 (0.68) | 13.98 (7.01) |
| Female proposers | 5.93 (0.76) | 14.32 (6.09) |

Table 4.3: Average price and waiting time of male and female proposers in the Kiel market for budget travel by train (std. dev is given in brackets)

### 4.2.2 Characterization of the market

This section provides a qualitative analysis of the market. On the one hand, the market for budget travel by train is a market situation where prices are expected to be largely influence by the supply and demand. On the other hand, as provided below in section 4.3, we find that the deadline imposed on the bargainers indeed leads to higher prices than in a situation without a deadline (section 4.3 provides evidence that the average price of a travel using the S-H ticket is cheaper when the responder contact the proposer in advanced). That evidence supports that the market can be characterized, at least to some extent, as an UG.

We start our analysis with a comparison between the the Kiel market for budget travel by train and the UG: In the classic UG the ultimatum stems from the strategy space of the responder (accept or reject). In the train market, however, it stems from the deadline imposed on the bargainers by the trains' departure time. The idea that the existence of a deadline would turn even an unstructured bargaining game into an ultimatum bargaining game was already tested in the

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<sup>12</sup> $P < 0.05$  between the revenue's series with a price of €7 and each of the other series of revenues.

## 4.2 The Kiel Market for Budget Travel by Train

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laboratory in the reverse ultimatum game by [Gneezy \*et al.\* \(2003\)](#).<sup>13</sup> In contrast to laboratory experiments of the UG, the bargaining in the train station is done face-to-face. Nevertheless, it is sensible to assume that during the time of observations (Monday-Thursday, 15:50-19:21) proposers do not meet the responders frequently. The fact that proposers are observed by other people may decrease their price offers to responders. [Haley & Fessler \(2005\)](#) found that when a drawing of a pair of eyes is shown on the screen in a dictator bargaining game<sup>14</sup>, it increases positive giving by the proposers from 55% to 88%. The natural context in the train market (in comparison to the UG) may increase the price offers, since [Hoffman \*et al.\* \(1996\)](#) find that offers in UG decrease significantly when property rights are established ([Hoffman \*et al.\* \(1996\)](#) used a knowledge quiz to select "sellers" and "buyers"). A comparison with the classic UG experiment is given in Table 4.4.

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<sup>13</sup>The reverse ultimatum game involves two players. Player A divides a pie of size  $x$  between himself and another Player B. Player B, then, decides whether to accept and receive the division proposed by Player A, or to reject the offer. If Player B rejects the offer, Player A can either offer another division, as long as that offer gives Player B a strictly higher share of the pie, or refuse to offer and end the game. In this last case both players receive zero. Thus, the game ends either when Player B accepts an offer, or when, following a rejection, Player A refuses to make another offer.

<sup>14</sup>The dictator bargaining game involves two players. Player A divides a pie of size  $x$  between himself and another Player B.

## 4.2 The Kiel Market for Budget Travel by Train

|                                   | UG   | Train  |
|-----------------------------------|--|--|
| Type of agents                    | Only proposers and responders                    | Mainly Proposers and responders  |
| Number of responders per proposer | One  | Many   |
| Competition between proposers     | No   | To some extent   |
| Actions                           | Proposers offer, responders can accept or reject | Theoretically can also bargain   |
| Visual contact                    | No   | Face-to-face   |
| Repeated game                     | No   | Kiel is large, also depends on time of the day                           |
| Ultimatum                         | Accept or reject                                 | Time to departure (51% of proposers left less than 10 min. to departure) |
| Context                           | Artificial                                       | Natural  |
| Money amount                      | Mostly small (gain about 5-10\$)                 | Relatively small (save about 5-20\$)                                     |

Table 4.4: A comparison between the Ultimatum Game (UG) and the Kiel market for budget travel by train

The question in whether we describe a market situation or a kind of an UG, is best illustrated using the following Although there are similarities between the UG and the Kiel market, we are, nevertheless, dealing with a market situation.

That means that the price offers are bounded by a certain range. We have not observed a price above €10 (or below €3). That may imply that competition between proposers prevents proposers to offer prices above €10.<sup>15</sup> The lower bound on the price offers may be determined by the minimum revenue a proposer seeks, otherwise, he would act as a responder. Nevertheless, competition is not intense when prices are below €10<sup>16</sup>, as presented in Figure 4.4.

<sup>15</sup>When we were acting as proposers in the market (see section 4.4), we could not enter the market with a price higher than €10 in the presence of other proposers because responders were looking for a better offer.

<sup>16</sup>When a proposer offers to take a responder for a specified price, other proposers do not, usually, reveal their prices even when they are lower than the price offered (maybe due to an unwritten behavior code).

### 4.3 The Ride-Share Community

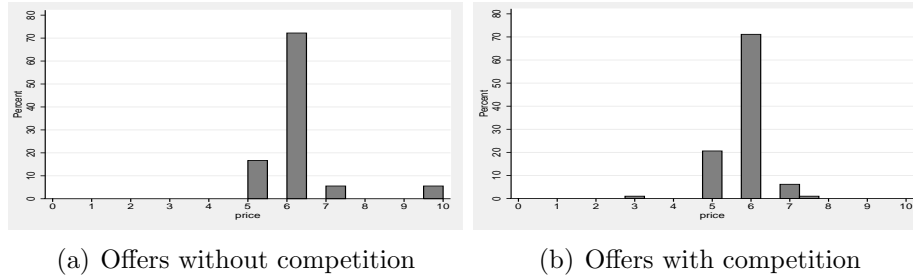


Figure 4.4: Figure 4.4(a) presents the distribution of price offers in the market when there is only one proposer in the market. Figure 4.4(b) presents the distribution of price offers in the market when there are, at least, two proposers in the market.

Formally, using an F-P test for comparison between the series of prices when there is one proposer (no competition) in the market and when there are at least two proposers (competition), we find no significant difference ( $P = 0.36$ ) between the series.

### 4.3 The Ride-Share Community

A large market for budget travel by car in Germany is the online ‘ride-share community’ (<http://www.mitfahrgelegenheit.de/>). The web-site allows proposers to post offers to take passengers in a certain route (e.g. Kiel-Hamburg), at a certain date, for a certain price. Thus, the web-site provides a list of names and prices for each route and date (see Figure 4.9 in the Appendix), so that responders can look for an offer. Although the offered price could depend on the number of passengers, it is almost always a specified price that does not depend on the number of passengers (794/812  $\approx$  98% of the offers in the Kiel-Hamburg route).<sup>17</sup> A responder can either accept the offer and contact the proposer, or reject and search for another offer. There are, on average, more than one proposer per hour, and since responders contact proposers in advance this market entails no ultimatum. We observed the market for a period of 5 weeks (Monday-Thursday) between May, 5, 2008 and June, 5, 2008 (a total of 812 offers, 68% are made

<sup>17</sup>Only 64% of the proposers post their price in the web-site. However, we called the other 36% to see whether their prices depend on the number of passengers.

### 4.3 The Ride-Share Community

by males). The distribution of price offers in this market (in comparison with the Kiel market for budget travel by train) is presented in Figure 4.5, while the average prices and the average number of proposers per hour are presented in Figure 4.6.

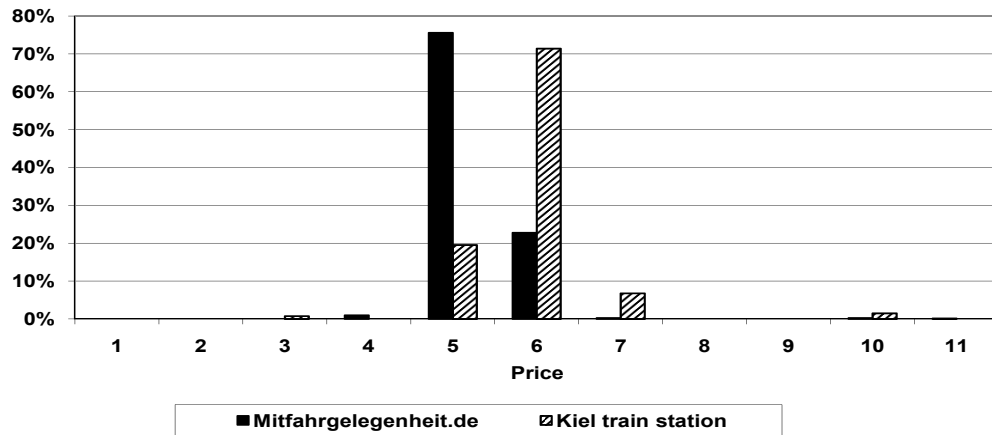


Figure 4.5: Distribution of prices in the ride-share community and in the Kiel market for budget travel by train

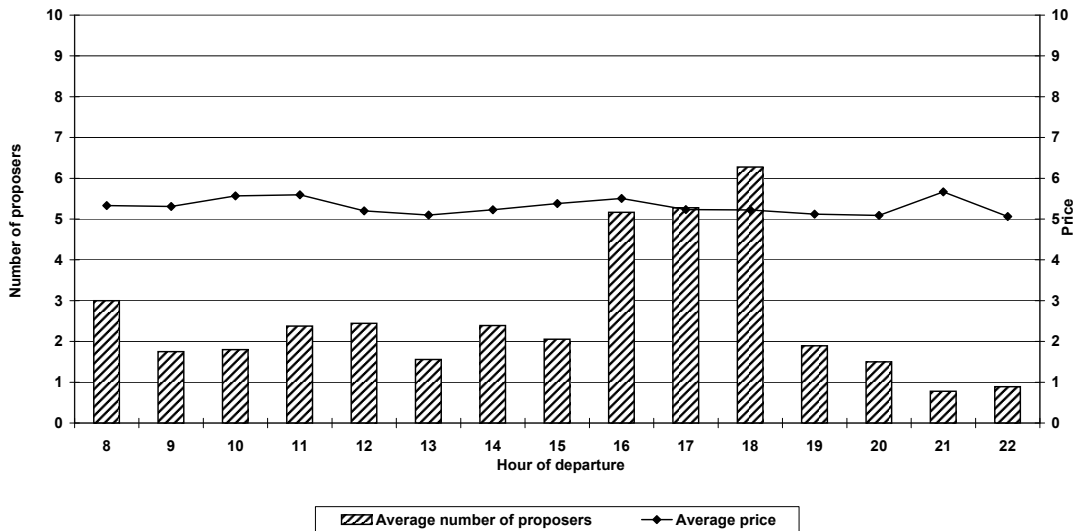


Figure 4.6: Average number of proposers, and average price per hour in the ride-share community

From Figure 4.5 we learn that the price of €5 is the most common offer



### 4.3 The Ride-Share Community

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(average price: 5.25, std. dev: 0.57, min price: 4, max price: 12). This price is lower than in the market for budget travel by train<sup>18</sup>, possibly due to more competition (more proposers per hour), or due to the absence of ultimatum in the ride-share community. Moreover, the marginal cost of taking a passenger is unknown to us. If a proposer only cares about monetary gains, then under the assumption that the proposer has to drive anyway, his marginal cost is about zero. Some people, however, get negative (or positive) utility from having someone else in the car. Thus, in order to learn about the price offers in the market, we made a short survey, calling a total of 30 proposers and asking them why they charge the price offered. Of those 30 proposers, 19 (63%) offered a price of €5, 8 (26%) offered a price of €6, 2 (6%) offered a price of €4, and one proposer (3%) offered a price of €7.<sup>19</sup> 13 proposers (43%) decide by looking at other offers in the web-site (proposers who offered €5 and €6). 12 proposers (40%) stated that they charge a price that covers their costs of gasoline (proposers who offered €4,5 and €6). The two proposers who charge €4 behave as in a price (à la Bertrand) competition (by charging that price they manage to take 4 passengers each ride). 4 proposers (13%) used the terms “fair” or “reasonable”.

The ‘ride-share community’ web-site also allows proposers to post offers to travel using the S-H ticket. We observed 41 offers (4% of the total number of offers) to travel using the S-H ticket. 20 offers (48%) did not specify a price (cost-sharing offers). Of the other 52% that did specify a price, we count 16 offers of €5, and 5 offers of €6 (the average price offered is €5.23). These prices are significantly smaller than the prices observed in the train station ( $P = 0.00$ , two sided F-P test), but not different from the distribution of prices in the ride-share community ( $P = 0.53$ , two sided F-P test).

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<sup>18</sup>Using an F-P test, comparing between the series of prices in the Kiel train station and in the ride-share community, we find that the series of prices are significantly different from each other ( $P = 0.00$ ).

<sup>19</sup>His answer to our question was something like: “That’s the way it is”.

## 4.4 An Experimental Test of Responder Behavior

So far, we have passively observed the Kiel market for budget travel by train.<sup>20</sup> We have learned that the prevailing price in the market is €6. Moreover, 91% of the price offers were of €5 or €6. In order to get some insights about responders' behavior to different price offers, we entered the market as proposers. Initially, we aimed at revealing the observed demand for travel using the S-H ticket for prices higher than €7. For this purpose we employed four research assistants (three females and one male) to behave as proposers in the market. They documented the time they offered and the gender of the responders. The experimental procedure was as follows: The research assistants bought the S-H ticket immediately upon arriving at the train station. They offered to take responders for a specified price on the same days and hours as described in section 4.2 (Mo-Thu, 15:50-19:21). To motivate them to approach as many responders as possible, the research assistants could keep the money they have earned as proposers in addition to their hourly salary. They did not provide information about the experiment to the responders at any point. The responders could only know that the proposer is traveling to Hamburg and would come back later using the S-H ticket. In total, our research assistants entered the market as proposers during 35 different days, between June, 2008 and October, 2008. On each day they offered to take responders for a specified price. The number of days per price is given in Table 4.5.

|                          |   |    |    |    |    |    |    |    |
|--------------------------|---|----|----|----|----|----|----|----|
| Number of days per price | 6 | 7  | 6  | 5  | 2  | 4  | 1  | 4  |
| Price offered            | 8 | 10 | 12 | 13 | 14 | 15 | 17 | 18 |

Table 4.5: Number of different days for each price

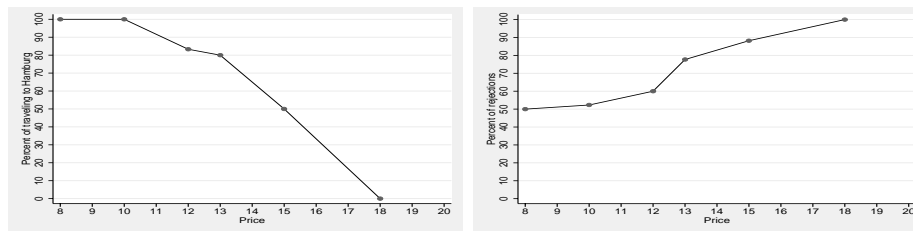
Although we initially aimed at revealing the demand for travel using the S-H ticket, we could not compare the results of prices higher than €10 with the results of lower prices. The reason is that with prices higher than €10, we could only enter the market in the absence of other proposers. This is because at high prices

<sup>20</sup>In fact, we used the data we generated (by behaving as proposers in the market and offering to take responders with our ticket for €8 and €10) to create the demand schedule presented in Figure 4.3.

## 4.4 An Experimental Test of Responder Behavior

responders are looking for a better offer. Therefore, for prices higher than €10, we only aimed at finding the price where the demand is equal to zero (i.e. no passenger is willing to come with us). Although the prevailing price in the market is €6, only at the price of €18 we did not find a single responder to join us. This means that, *at least*, some responders behave as profit maximizers as economic theory predicts.

Although our offers at these high prices are not completely comparable with each other we, nevertheless, used two measures to assess the effect of price on the number of passengers. (i) The percentage of days we traveled to Hamburg at each price (i.e. days we found, *at least*, one passenger who was willing to pay the specified price). (ii) The rejection rate of offers at each price. The results are illustrated in Figure 4.7.



(a) Percentage of travels to Hamburg per price offered (b) Percentage of rejection of offers per price offered

Figure 4.7: Figure 4.7(a) displays the percentage of days we found, at least, one responder who was willing to travel with us to Hamburg at the price offered. Figure 4.7(b) displays the rejection rates (number of rejection divide by the total number of offers) at the price offered.

Figure 4.7 illustrates that when the price increases, the percentage of travels decreases monotonically and the rejection rate increases monotonically. Finally, we estimated a Logit model, to see whether the price, time pressure, and the difference in gender of proposers and responders affect the probability that a responder will accept an offer.<sup>21</sup> The results are presented in Table 4.6.

<sup>21</sup>In an additional Logit estimation we find that responder's gender is not significantly correlated with the probability to accept an offer.

| Variable                | Coef. (Std. Err.)  |
|-------------------------|--------------------|
| Price offered           | -0.32***<br>(0.08) |
| Gender interaction      | -0.13<br>(0.46)    |
| Time pressure           | 0.83*<br>(0.46)    |
| Constant                | 2.77<br>(1.02)     |
| LR test (K-1)           | 23.36***           |
| McFadden's Pseudo $R^2$ | 0.16               |

\*, \*\*, \*\*\* denote significance at the 10%, 5%, and 1% levels, respectively

Table 4.6: Logit estimation testing whether the probability to accept an offer is correlated with the price, the gender interaction (dummy variable gets the value 1 when the genders of a proposer and a responder are different), and a time pressure (dummy variable gets the value 1 when offer was made less than 10 minutes to the train departure)

Table 4.6 indicates that, as expected, the probability to accept an offer is lower when the price offered is higher. In addition, the probability to accept an offer is higher when the offer is made right before the train departure time. This result is in line with [Gneezy \*et al.\* \(2003\)](#). They find that most agreements, in a reverse ultimatum game, occur just before the time limit expires.

## 4.5 Discussion

This note describes the Kiel market for budget travel by train. There are several reasons for investigating this market. It provides, to some extent, a natural investigation of an ultimatum bargaining situation. This market also allows the investigation of the behavior of bargainers in a situation restricted by a deadline.

We find that offers are lower than the profit-maximization price. In addition, a large portion of the proposers who did not get four passengers leave the market long before the train departure time, thus, not behaving as profit-maximizers. The result that the distribution of prices is similar when there is only one proposer in the market and when there are, at least, two proposers may imply that the market price of €6 is used as a coordination device (focal-point). In other words,

when a price of €6 prevails in the market and it is common knowledge, responders expect proposers to offer that price, and proposers expect responders to accept that price offer. The focal-point explanation was also suggested by Güth *et al.* (2001) to explain the large portion of people who choose equal-split in an UG experiment. Finally, taking the role of proposers, only at the price of €18 we could not find any responder to travel with us. This means that, at least, some responders behave as profit maximizers.

## Acknowledgements

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## 4.6 Appendix to Chapter 4

### 4.6.1 Screens

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Figure 4.8: The opening page at <http://www.mitfahrgelegenheit.de/>

## 4.5 Discussion

| Keine passende Fahrt gefunden? Dann nimm doch die Bahn!  <b>BAHN</b> |      |         |              |           |                |   |
|---|------|---------|--------------|-----------|----------------|---|
| Typ   | von  | nach    | Zeitpunkt    | Uhrzeit   | Kosten         | Infos   |
| Angebot   | Kiel | Hamburg |              |           | ab 26.- €/Tag* | <b>AVIS</b>   |
| Angebot   | Kiel | Hamburg | Mo, 16.02.09 | 03.30 Uhr |                |   |
| Angebot   | Kiel | Hamburg | Mo, 16.02.09 | 04.30 Uhr | VHS            |   |
| Angebot   | Kiel | Hamburg | Mo, 16.02.09 | 05.00 Uhr | VHS            |    |
| Angebot   | Kiel | Hamburg | Mo, 16.02.09 | 06.00 Uhr | 6.- EUR        |    |
| Angebot   | Kiel | Hamburg | Mo, 16.02.09 | 06.00 Uhr | VHS            |    |
| Angebot   | Kiel | Hamburg | Mo, 16.02.09 | 06.15 Uhr | 5.- EUR        |   |
| Angebot   | Kiel | Hamburg | Mo, 16.02.09 | 06.15 Uhr | 5.- EUR        |       |
| Angebot   | Kiel | Hamburg | Mo, 16.02.09 | 06.15 Uhr | 5.- EUR        |    |
| Angebot   | Kiel | Hamburg | Mo, 16.02.09 | 06.15 Uhr | VHS            |   |
| Angebot   | Kiel | Hamburg | Mo, 16.02.09 | 06.15 Uhr | 6.- EUR        |    |
| Angebot   | Kiel | Hamburg | Mo, 16.02.09 | 06.30 Uhr | VHS            |    |
| Angebot   | Kiel | Hamburg | Mo, 16.02.09 | 06.45 Uhr | 5.- EUR        |    |
| Angebot   | Kiel | Hamburg | Mo, 16.02.09 | 06.45 Uhr | VHS            |    |
| Gesuch  | Kiel | Hamburg | Mo, 16.02.09 | 06.45 Uhr | VHS            |   |
| Angebot   | Kiel | Hamburg | Mo, 16.02.09 | 07.00 Uhr | 6.- EUR        |    |
| Angebot   | Kiel | Hamburg | Mo, 16.02.09 | 07.00 Uhr | VHS            |    |
| Angebot   | Kiel | Hamburg | Mo, 16.02.09 | 07.15 Uhr | 5.- EUR        |   |
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| Angebot   | Kiel | Hamburg | Mo, 16.02.09 | 07.30 Uhr | 5.- EUR        |    |
| Gesuch  | Kiel | Hamburg | Mo, 16.02.09 | 07.30 Uhr | VHS            |    |
| Angebot   | Kiel | Hamburg | Mo, 16.02.09 | 07.30 Uhr | VHS            |    |
| Angebot   | Kiel | Hamburg | Mo, 16.02.09 | 07.45 Uhr | 5.- EUR        |    |
| Gesuch  | Kiel | Hamburg | Mo, 16.02.09 | 07.45 Uhr | VHS            |    |
| Angebot   | Kiel | Hamburg | Mo, 16.02.09 | 08.00 Uhr | 5.- EUR        |    |
| Angebot   | Kiel | Hamburg | Mo, 16.02.09 | 08.00 Uhr |                |   |
| Angebot   | Kiel | Hamburg | Mo, 16.02.09 | 08.00 Uhr | VHS            |    |

Figure 4.9: List of offers at <http://www.mitfahrgelegenheit.de/>

# Conclusions

This section briefly summarizes the results of chapters 1 to 4. The first two chapters of this thesis deal with the issue of subject pool selection in Cournot Oligopoly experiments. Chapter 1 is motivated by the general question in whether it is justifiable to ignore personality traits of subjects playing the role of firms (or firms' managers) in laboratory experiments. The main objective of this chapter is to test whether personality traits (as measured by the NEO-PI-R) affect behavior in a random-matching Cournot Duopoly experiment. We find that in the absence of experience (in the first period of the experiment) high conscientiousness (and female sex) is correlated with collusion. However, from the second period of the experiment onwards, personality traits do not affect the subjects' behavior. In view of the personality-situation controversy, this result supports situation as a main determinant of behavior (at least in the specific situation tested). This study also finds that a larger cooperation ratio (the ratio between the collusive and the Cournot-Nash profits) and, as a result, a larger vulnerability ratio (the ratio between the Cournot-Nash profit and the profit a player receives when choosing the cooperative action while the other player deviates) does not yield more collusion than in previous studies. In fact, we observed higher frequency of quantities within the rivalistic range than in previous studies.

Chapter 2 presents a study that follows the design of [Huck \*et al.\* \(2004\)](#) to investigate whether Malaysian managers behave differently than Malaysian students (and German students) in a Cournot Triopoly experiment. By and large, we find that the Cournot-Nash equilibrium is a good predictor for subject performance in Cournot Triopoly experiments (at least, the quantities selected by the three subject pools are closer to the Nash quantity than to the other two benchmark quantities). Albeit, we find that Malaysian students perform significantly more competitively than the Malaysian managers and the German



students. This result casts doubts upon one aspect of external validity in Cournot Oligopoly experiments, namely, the extent to which we can generalize results of experiments conducted with students to the behavior of managers in such situations. In addition, we find that gender affects behavior: For the German student sample we find that females behave more cooperatively than males, while the opposite holds for the Malaysian samples. This result supports findings by [Gneezy \*et al.\* \(2009, forthcoming\)](#) suggesting that societal structure is crucially linked to observed gender differences in behavior.

Chapter 3 provides a direct test in the laboratory for the theoretical prediction by [Requate & Unhold \(2001\)](#) that when the regulator commits herself *ex-ante* to the level of permits, the initial allocation of permits (auctioning vs. grandfathering), or the specific auction design (in our case, an ascending clock auction vs. a single unit double auction), should not affect the firms' incentives to invest in advanced technology in a market characterized by many small asymmetric firms. In particular, we center on three allocation-auction policies: auctioning off permits through an ascending clock auction, grandfathering permits and allocating them through a single unit double auction, and grandfathering permits and allocating them through an ascending clock auction. The results confirm the theoretical findings of [Requate & Unhold \(2001\)](#) that regarding optimal adoption of the advanced technology, all three policies are equivalent. We also find that these policies yield, similar results regarding total social welfare. We find, however, weak evidence that the single unit double auction is more efficient than the ascending clock auction in the optimal allocation of permits (having lower total abatement costs given the investment decision).

Chapter 4 describes the Kiel market for budget travel by train, thus, providing a natural investigation of a market situation having some features of the ultimatum bargaining game. We find that offers are lower than the profit-maximization price. In addition, a large portion of the proposers who did not get the maximum number of passengers leave the market long before the train departure time, thus, not behaving as profit-maximizers. The result that the distribution of prices is similar when there is only one proposer in the market and when there are, at least, two proposers may imply that the market price of €6 is used as a coordination device (focal-point). Finally, taking the role of responders, we find that, at least, some responders behave as profit maximizers.

Lastly, Appendix A presents a bootstrap approach to determine critical values for the DQ-test (Engle & Manganelli, 2004b). It is shown to have preferable empirical size features than the asymptotic approximation of the test in finite samples. It is also preferable to a likelihood ratio test based on Logit regressions (Clements & Taylor, 2003; Patton, 2006).

In summary, although the emergence of experimental economics dates back to the second half of the previous century, it has especially started booming in the last two decades. Nowadays, experiments are being used in almost every field of economics. Nevertheless there is still much to learn from experiments, especially in the topics presented in this thesis. Although experiments on Cournot Oligopoly have been conducted since the late 1950's (Hoggatt; Selten & Sauermann), there is no consensus about the optimal design for such experiments, especially regarding the following questions: Which information should be given to subjects and how should this information be presented? Which subject pool best represents firms? How many subjects should represent a single firm? Should we allow communication between subjects during the experiment? Only by testing the effect of different parameters in the experimental design (e.g. communication vs. no communication, number of subjects assigned to one firm, etc.), may we come out with a design that genuinely describes the Cournot Oligopoly market structure. Relating to chapter 3, although much experimental research has been done in the topic of permit markets, the vast majority of this research focuses on the static efficiency of the different policy instruments, and only few studies considered the dynamic efficiency of development or adoption of advanced technology. This is the case even though theorists started ranking environmental policy instruments according to their ability to facilitate adoption and development of advanced technology, more than two decades ago, around the second half of the 1980's (Downing & White; Malueg; Milliman & Prince). Thus, further research focusing on the incentives to adopt and develop advanced technologies in pollution markets is required in order to provide feedback for the theories. Finally, the importance of field experiments to economic research should not only be measured by their direct contribution from the published works<sup>22</sup>, but also by their indirect contribution owing to the process of searching for naturally occurring sit-

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<sup>22</sup>For a discussion about the merits and contributions of field experiments to economic research see List (2006).

## Conclusions

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uations that could be better understood by means of an experiment. This search process inspires researchers to observe everyday phenomena with a “child-like” inquisitiveness and curiosity.

# Appendix A

## A Bootstrap Approach to Value-at-Risk Diagnostics

### A.1 Introduction

Value-at-risk (VaR) is a widely used measure of portfolio risk. Formally, suppose that  $\{y_t\}_{t=1}^T$  is a time series of speculative returns. At coverage rate  $\alpha$  and given the information set available in time  $t - 1$ ,  $\Omega_{t-1}$ , the conditional VaR, denoted  $\text{VaR}_t(\alpha)$ , is the quantile such that

$$\text{Prob}[y_t < -\text{VaR}_t(\alpha)|\Omega_{t-1}] = \alpha. \tag{A.1}$$

Although the VaR concept is easy to grasp, its calculation is challenging since the ‘true’ conditional distribution of returns is typically unknown.<sup>1</sup> To evaluate competing specifications, [Christoffersen \(1998\)](#) suggests a framework for testing VaR models that focuses on two conditions, *unconditional coverage* and *independence*. While the former implies that the frequency of actual return shortfalls, so-called VaR *hits* equals  $\alpha$ , the latter states that the event of a return shortfall in period  $t$  is uncorrelated with information available in  $\Omega_{t-1}$ . [Engle](#)

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<sup>1</sup>For a review on the numerous VaR models see [Engle & Manganelli \(2004a\)](#).

& Manganelli (2004b) propose a regression based Dynamic Quantile (DQ) test linking current to past violations.

The fact that the DQ approach exploits a common linear regression for binary dependent variables provoked competing VaR diagnostics based on logit regressions (Clements & Taylor, 2003, and Patton, 2006). Depending on the nominal VaR coverage  $\alpha$ , the postulated asymptotic distribution of the DQ-test might work only for very large sample size. Then, resampling techniques could be considered as a promising alternative to achieve faster convergence of actual to nominal significance levels. In this study we propose a bootstrap design for the implementation of the DQ-test which is similar to a resampling approach recently introduced by Herwartz & Xu (2009). A Monte Carlo study shows that in finite samples the bootstrap outperforms inference based on critical values taken from a  $\chi^2$ -distribution.

In the next section we sketch the DQ-test and the logit based likelihood ratio (LR) test. The bootstrap procedure is also sketched in Section A.2. A Monte Carlo comparison of alternative inferential strategies is provided in Section A.3. Section A.4 concludes.

## A.2 VaR Diagnosis

To derive the DQ-test, define a process of centered *hits*,

$$z_t(\alpha) = I(y_t < -\text{VaR}_t(\alpha)|\Omega_{t-1}) - \alpha, \quad (\text{A.2})$$

where  $I(\bullet)$  is an indicator function. Hence, for a well specified VaR model, unconditionally, the hit function is  $1 - \alpha$  with probability  $\alpha$  and  $-\alpha$  with probability  $1 - \alpha$ . To assess dynamic accuracy, consider the following linear regression for given presample values

$$z_t(\alpha) = \beta_0 + \sum_{i=1}^p \beta_i z_{t-i}(\alpha) + \mathbf{x}'_{t-1} \boldsymbol{\theta} + u_t, \quad t = 1, \dots, T. \quad (\text{A.3})$$

In (A.3)  $\mathbf{x}_{t-1} \in \Omega_{t-1}$  is a  $q$ -dimensional vector of predetermined variables. Let  $\mathbf{z}_t = (1, z_{t-1}, \dots, z_{t-p}, \mathbf{x}'_{t-1})'$  and, accordingly,  $\boldsymbol{\delta} = (\beta_0, \boldsymbol{\beta}', \boldsymbol{\theta})'$  with  $\boldsymbol{\beta} = (\beta_1, \dots, \beta_p)'$ . For the purpose of VaR diagnosis the joint null hypothesis  $H_0 : \boldsymbol{\delta} = 0$  is tested against the alternative  $\boldsymbol{\delta} \neq 0$ . Engle & Manganelli (2004b) propose the Wald statistic

$$DQ_\alpha = \frac{\hat{\boldsymbol{\delta}}' \mathbf{Z}' \mathbf{Z} \hat{\boldsymbol{\delta}}}{\alpha(1-\alpha)} \xrightarrow{d} \chi^2(p+q+1). \quad (\text{A.4})$$

In (A.4)  $\mathbf{Z} = (\mathbf{z}_1, \mathbf{z}_2, \dots, \mathbf{z}_T)'$  collects the explanatory variables and  $\hat{\boldsymbol{\delta}}$  is the vector of OLS parameter estimates. The asymptotic distribution in (A.4) holds under  $H_0$ .

Clements & Taylor (2003) and Patton (2006) point out that the dependent variable in (A.3) is binary and, thus, a logit (or probit) regression model is more appropriate to infer on the explanatory content of the right hand side variables in (A.3). To set out the LR approach define an uncentered *hit* function

$$\tilde{z}_t(\alpha) = I(y_t < -\text{VaR}_t(\alpha) | \Omega_{t-1}). \quad (\text{A.5})$$

The suggested LR statistic with distribution under  $H_0$  is

$$\begin{aligned} LR_\alpha &= -2 \sum_{t=1}^T \Delta l_t, \\ \Delta l_t &= l_t(\beta_0 = \ln(\alpha/(1-\alpha)), \boldsymbol{\beta} = 0, \boldsymbol{\theta} = 0 | \tilde{z}_t, \tilde{\mathbf{z}}_t) - l_t(\boldsymbol{\delta} | \tilde{z}_t, \tilde{\mathbf{z}}_t) \\ &\xrightarrow{d} \chi^2(p+q+1), \end{aligned} \quad (\text{A.6})$$

where  $\tilde{\mathbf{z}}_t = (1, \tilde{z}_{t-1}, \dots, \tilde{z}_{t-p}, \mathbf{x}'_{t-1})'$  is the vector of explanatory variables and  $l_t$  is the log likelihood function to be maximized, e.g. by means of a logit regression.

### A.2.1 Resampling the DQ-statistic

Conditional on some small  $\alpha$ ,  $\alpha = 0.01$  say, an event  $z_t(\alpha) = 1 - \alpha$  is rarely observed. In this case the actual significance levels of the statistic in (A.4) might dif-

fer substantially from the nominal level in finite samples. In such cases bootstrap algorithms could be seen as a promising alternative to first order asymptotic approximations that often show faster convergence of actual to nominal significance levels. Recently, [Herwartz & Xu \(2009\)](#) have introduced a bootstrap procedure that could be adopted for VaR diagnosis. To determine critical values for  $DQ_\alpha$  with nominal significance level  $\gamma$ , it consists of the following steps:

1. Draw bootstrap samples  $\{z_t^*(\alpha)\}_{t=1}^T$  from  $\{z_t(\alpha)\}_{t=1}^T$  without replacement.
2. Determine bootstrap estimators ( $\hat{\delta}^*$ ) for the sample  $\{z_t^*(\alpha), \mathbf{z}_t\}_{t=1}^T$  and the bootstrap DQ-statistic

$$DQ_\alpha^* = \frac{\hat{\delta}^{*'} \mathbf{Z}' \mathbf{Z} \hat{\delta}^*}{\alpha(1 - \alpha)}.$$

3. Steps (1) and (2) are performed  $B$  times with  $B$  sufficiently large. Reject  $H_0$  with if  $DQ_\alpha$  exceeds the  $(1 - \gamma)$  quantile of  $\{DQ_\alpha^*\}_{b=1}^B$ .

## A.3 Monte-Carlo Study

This section provides a performance comparison of the bootstrap approach to the DQ-test with the asymptotic approximations of DQ and the logit LR-test. Throughout, MC exercises cover 10000 replications with the number of bootstrap draws  $B = 499$ . Empirical rejection frequencies are determined for distinct VaR coverage levels  $\alpha$  (ordered from 0.5% to 5%), for nominal significance levels  $\gamma = 1\%$ , 5% and sample sizes  $T = 3000, 5000, 10000$ .

### A.3.1 The simulation design

For simulations under  $H_0$   $z_t(\alpha)$  is determined by means of iid Gaussian variates. Let  $\Phi(\bullet)$  denote the Gaussian distribution function. Then, centered and uncentered hit processes are, respectively,

$$z_t(\alpha) = I(\xi_t < \Phi^{-1}(\alpha)) - \alpha, \quad \tilde{z}_t(\alpha) = I(\xi_t < \Phi^{-1}(\alpha)), \quad \text{with } \xi_t \sim iid N(0, 1). \tag{A.7}$$

To investigate empirical power features ( $H_1$ ), the  $\xi_t$  process in (A.7) is replaced by a first order autoregression with unconditional unit variance, i.e.  $\xi_t = 0.1\xi_{t-1} + \zeta_t$ ,  $\zeta_t \sim iidN(0, 0.99)$ .

An often raised caveat of Monte Carlo results is their dependence upon the data generating processes used for simulation. For the case of simulating VaR *hits* under the null hypothesis of a well specified risk model, it is worthwhile to point out that the design in (A.7) matches the null hypothesis in a one-to-one manner. Competing, well specified VaR models imitating the null hypothesis would not deliver systematically different empirical size features of test procedures. The data generating mechanism applied to imitate a poor VaR specification ( $H_1$ ) lacks parametric rigor, but it will be interesting to investigate how alternative diagnostic tools cope with a ‘nonparametric’ alternative.

Specifying equation (A.3) we consider an autoregressive model of order  $p = 5$ , i.e.

$$z_t(\alpha) = \beta_0 + \sum_{i=1}^5 \beta_i z_{t-i}(\alpha) + u_t. \tag{A.8}$$

### A.3.2 Empirical size and power

Simulation results are documented in Table A.1. Conditional on a small nominal VaR coverage ( $\alpha = .005, .01, .015$ ) common asymptotic approaches to VaR diagnosis either show huge empirical size distortions or deserve rather large dimensional sample information. For instance, at the 5% nominal significance level, the empirical levels of  $DQ_{.01}$  and  $LR_{.01}$  are 11.25% and 1.63% ( $T = 3000$ ) or 6.75% and 3.70% ( $T = 10000$ ), respectively. While size distortions for the  $DQ_\alpha$  test amount to oversizing throughout, the LR approach features both significant over- and undersizing depending on the VaR coverage subjected to testing. Throughout, generating critical values for  $DQ_\alpha$  by means of resampling offers empirical size levels which are considerably closer to the nominal level of the test. To mention an extreme case compare the empirical size for the  $DQ_{.005}$  and its bootstrap counterpart which are 19.29% and 3.47% ( $T = 3000$ ) or 12.63% and 5.03% ( $T = 10000$ ), respectively. For diagnosing  $VaR_t(0.025)$  specifications boot-



strap inference yields for all considered sample sizes empirical significance levels insignificantly close to  $\gamma = 0.05$ . It is noteworthy that for most practical issues the considered nominal VaR coverage is typically small, 1% or less say.

As documented in the bottom panel of Table A.1 all test procedures show empirical power since rejection frequencies are uniformly higher under the non-parametric alternative in comparison with  $H_0$ . In light of most preferable size features of the resampling approach the latter is clearly recommendable for financial practice.

## A.4 Conclusion

A bootstrap approach to determine critical values for the DQ-test ([Engle & Manganelli, 2004b](#)) is shown to have preferable empirical size features than the asymptotic approximation of the test in finite samples. It is also preferable to a likelihood ratio test based on logit regressions ([Clements & Taylor, 2003](#); [Patton, 2006](#)). The merits of the resampling scheme are particularly relevant for diagnostic checking of VaR models targeting at a small nominal coverage of 0.5%, 1% or 1.5%.

## A.4 Conclusion

|                 | $T$   | $\alpha$ |       |       |       |       |       |       |       |
|-----------------|-------|----------|-------|-------|-------|-------|-------|-------|-------|
|                 |       | 0.5%     | 1%    | 1.5%  | 2%    | 2.5%  | 3%    | 4%    | 5%    |
| Size estimates  |       |          |       |       |       |       |       |       |       |
| $DQ_\alpha$     | 3000  | 19.29    | 11.25 | 7.77  | 6.54  | 6.11  | 5.78  | 4.72  | 5.17  |
| $LR_\alpha$     |       | 0.81     | 1.63  | 2.58  | 4.31  | 6.58  | 6.73  | 6.30  | 5.75  |
| $DQ_\alpha^*$   |       | 3.47     | 4.12  | 4.47  | 4.71  | 4.82  | 4.93  | 4.43  | 4.80  |
| $DQ_\alpha$     | 5000  | 9.03     | 8.70  | 6.56  | 6.09  | 5.69  | 5.10  | 4.72  | 5.15  |
| $LR_\alpha$     |       | 0.84     | 2.45  | 4.42  | 6.77  | 7.08  | 6.94  | 5.66  | 5.79  |
| $DQ_\alpha^*$   |       | 4.14     | 4.58  | 5.15  | 5.05  | 5.15  | 4.84  | 4.61  | 5.11  |
| $DQ_\alpha$     | 10000 | 12.63    | 6.75  | 6.07  | 5.40  | 4.89  | 4.87  | 4.54  | 5.06  |
| $LR_\alpha$     |       | 1.46     | 3.70  | 6.84  | 7.14  | 6.02  | 5.70  | 5.06  | 5.28  |
| $DQ_\alpha^*$   |       | 5.03     | 5.13  | 5.29  | 4.59  | 4.54  | 4.81  | 4.82  | 5.15  |
| $DQ_\alpha$     | 3000  | 9.54     | 4.25  | 2.89  | 2.45  | 1.93  | 1.88  | 1.44  | 1.22  |
| $LR_\alpha$     |       | 0.14     | 0.26  | 0.35  | 0.66  | 1.04  | 1.38  | 1.23  | 1.43  |
| $DQ_\alpha^*$   |       | 0.62     | 1.01  | 0.89  | 0.92  | 0.96  | 1.05  | 1.11  | 0.94  |
| $DQ_\alpha$     | 5000  | 5.20     | 3.47  | 2.50  | 2.09  | 1.65  | 1.40  | 1.23  | 1.31  |
| $LR_\alpha$     |       | 0.11     | 0.38  | 0.51  | 1.10  | 1.41  | 1.54  | 1.23  | 0.99  |
| $DQ_\alpha^*$   |       | 0.85     | 1.04  | 1.11  | 1.17  | 1.04  | 0.88  | 1.01  | 1.12  |
| $DQ_\alpha$     | 10000 | 4.15     | 2.51  | 1.79  | 1.44  | 1.48  | 1.12  | 1.13  | 0.95  |
| $LR_\alpha$     |       | 0.18     | 0.59  | 1.24  | 1.34  | 1.18  | 1.10  | 1.25  | 1.00  |
| $DQ_\alpha^*$   |       | 0.97     | 0.98  | 0.98  | 1.07  | 1.19  | 0.90  | 1.19  | 0.92  |
| Power estimates |       |          |       |       |       |       |       |       |       |
| $DQ_\alpha$     | 3000  | 22.87    | 16.87 | 13.93 | 12.57 | 12.67 | 13.19 | 15.08 | 16.14 |
| $LR_\alpha$     |       | 1.33     | 3.07  | 5.55  | 8.41  | 10.75 | 11.33 | 11.91 | 14.39 |
| $DQ_\alpha^*$   |       | 4.55     | 7.11  | 8.77  | 9.97  | 10.68 | 11.97 | 14.59 | 16.34 |
| $DQ_\alpha$     | 5000  | 13.55    | 15.29 | 14.15 | 15.80 | 16.51 | 18.01 | 21.80 | 25.38 |
| $LR_\alpha$     |       | 1.68     | 5.18  | 8.89  | 11.48 | 13.28 | 14.72 | 16.86 | 20.86 |
| $DQ_\alpha^*$   |       | 6.94     | 8.88  | 11.68 | 14.48 | 15.45 | 17.60 | 22.64 | 26.22 |
| $DQ_\alpha$     | 10000 | 20.32    | 15.84 | 18.41 | 21.18 | 24.12 | 28.75 | 37.11 | 45.26 |
| $LR_\alpha$     |       | 3.10     | 8.98  | 13.59 | 15.95 | 19.13 | 22.80 | 30.74 | 39.91 |
| $DQ_\alpha^*$   |       | 8.78     | 12.57 | 17.08 | 20.46 | 24.42 | 29.28 | 38.49 | 47.00 |

Table A.1: Upper and medium panel: Empirical size estimates (in percentage points) for alternative nominal significance levels,  $\gamma = 5\%, 1\%$ , sample sizes  $T = 3000, 5000, 10000$  and VaR coverage levels  $\alpha = .005, .01, .015, .02, .025, .030, .040, .050$ .  $DQ_\alpha$  and  $LR_\alpha$  are asymptotic tests, and  $DQ_\alpha^*$  is the bootstrap counterpart of  $DQ_\alpha$ . The null hypothesis of a well calibrated VaR model is rejected if  $DQ_\alpha > \chi_6^2$ ,  $LR_\alpha > \chi_6^2$  or  $DQ_\alpha$  exceeds the  $(1 - \gamma)$  quantile of the corresponding bootstrap distribution. Bottom panel: Power estimates with respect to the nominal 5% significance level.

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## **Eidesstattliche Erklärung**

Ich erkläre hiermit, an Eides Statt, dass ich meine Doktorarbeit ‘Essays in Experimental Economics’ selbständig und ohne fremde Hilfe angefertigt habe und dass ich alle von anderen Autoren wörtlich übernommenen Stellen, wie auch die sich an die Gedanken anderer Autoren eng anlehenden Ausführungen meiner Arbeit, besonders gekennzeichnet und die Quellen nach den mir angegebenen Richtlinien zitiert habe.

Kiel, März 2009

Israel Waichman