UNIVERSITY OF TROMSØ UIT

TROMSØ UNIVERSITY BUSINESS SCHOOL

Anomalies

Confrontation between economic theory and economic experiments

Eirik Eriksen Heen

Master's Thesis in Economics

May 2011

i Preface

It is with mixed feelings I submit my master thesis and thereby ending student life. Though I am looking forward to the challenges that lie ahead, I will always look back at my life studying as interesting and a very enjoyable time. Now I look back on the choices that have led me to where I am now. I have to thank my sister and my father, for their "intervention" to stop me studying mathematics and starting with economics.

The work on my master thesis has been interesting, but challenging. I did not realize the scale of the topic I chose, and I am left with the feeling that I have merely scratched the surface of a huge field. The work has been interesting, so I hope that I will be given the opportunity to work with experiments once I graduate. This trip has had its ups and downs, from a feeling that everything would be figured out, to realizing that some results were wrong. If nothing else I have learned how to acquire new knowledge (pun intended) and to implement it.

There are a few people that I wish to thank for helping me with my thesis. First I would like to thank my supervisor Stein Østbye for helping me with everything from theoretical input to spell checking, I would not have come so far without him. I would like to thank my professors at the University of Tromsø, for their contribution to make me the economist that I am today. I would like to thank my parents for their love and support through my studies. A big thank you to everyone that has helped me with spell checking. Lastly I would like to thank five students that I shared an office with the first year of the master program. The first year was hard, but working together with you guys made it so much easier. Erik shouting "Ta en Kuhn Tucker" will forever be burnt into my memory.

Tromsø 13.05.2010

Eirik Eriksen Heen

ii Index

iii Table index

iv Figure Index

v Summary

This thesis discusses some of the anomalies observed in economics in general. Anomalies are classified as behavior that is contradictory to utility theory and/or Nash equilibrium behavior. The thesis reviews an experiment and classifies some of the anomalies detected through the experiment. The experiment is based on a two stage R&D game, allowing firms to cooperate in R&D. Risk is introduced for the firms through random variables. This thesis looks at models that can be used to explain anomalies. Most successful were the models allowing loss aversion and risk aversion when subjects cooperate in R&D. On the other hand, the attempts were less successful in most cases where subjects did not cooperate in R&D.

Keywords: Anomalies, Experimental Economics, R&D

1. Introduction

Have you ever wondered why a person would be risk averse with potential gains, but would be risk loving with potential losses? Or why people keep holding on to bad choices or bad portfolios? Or why people never would dream of selling that old wine they have stored in the cellar, but would never buy an equal one in the store? Why do people behave in a way that we as economists would consider to be irrational? These are some of the questions I will explore in this thesis.

Students of economics are taught to think of economics as an *a priori* science, with well-defined utility curves, rational agents and assuming that every agent has complete knowledge. Economists use the concept of *homo economicus,* a rational agent that care nothing for the welfare of others and have the ability to make perfect decisions, acting as if they used game theory in social interaction. Economics is a very theory-intensive field and less observation-intensive, perhaps more so than most other sciences. *"Consequently, we come to believe that economic problems can be understood fully just by thinking of them. After the thinking has produced sufficient technical rigor, internal coherence and interpersonal agreement, economists can then apply the results to the world of data".* (Vernon, 1989).

Most, if not all, economic models have the same axiomatic theory as a foundation. Most theory that has to do with the interaction of subjects uses Nash predictions as a metric for dominant strategies. How correct is the Nash prediction when confronted with data? And how rational are subjects? Are we consistent in some of the mistakes we make, or to paraphrase the title of a recent bestseller, are we "predictably irrational"? How can such observations carve the way for future economic interpretation?

This thesis will try to analyse the reasons that anomalies occur. Theory and empirical data are often not in accordance with each other. With many anomalies identified, can economists make better predictions about subjects' behavior? The question is then how to proceed. With so many observations and classifications of anomalies from experimental economics, the implication for theory is not clear? *"Attention then turns to the theory. What implication for economic theory do the experimental results have? Perhaps none."* (Samuelson, 2005). What can experimental economics then do for theory and what can theory do for experimental economics? This is the main reason why this field is interesting to investigate.

This master thesis is organized in the following way: chapter 2 discusses some of the reasons for conducting experiments. Chapter 3 explores some of the anomalies observed through experiments and review some relevant experiments conducted earlier. In chapter 4 the model and predictions are presented. This chapter also reviews some of the anomalies that might occur in the kind of experiments reported in this thesis and how to identify and classify these anomalies. Chapter 5 reports the results of the experiments and comment upon these results. Chapter 6 is an overall summary, with some discussion and conclusions based on the previous chapters.

1.1 Motivation

The motivation for this master thesis comes from participating as a subject in an experiment conducted by Stein Østbye and Matt Roelofs in spring 2008. The experimental testing of theory predictions immediately spiked my interest. I participated in as many seminars in the field as I could. Unfortunately, the University of Tromsø does not offer any courses in behavioral and experiment economics. In fall of 2010 I was invited to participate in another experiment conducted by Stein and Matt, this time assisting in the creation of the experiment. My main contribution was programming of the code for the computerized experiment, using z-Tree (Fischbacher, 2007). I also participated in discussions about the design and organization of the experiment. In the fall of 2010, I attended in the *5th Nordic Conference on Behavioral and Experimental Economics* in Helsinki. On the conference, Stein presented some preliminary results from our experiment that this master thesis is based on.

In the master program in economics at University of Tromsø the students can only choose one topic of interests to specialize in (except for the master thesis itself). I chose to read and write about experimental economics, to further my knowledge. After analysing the data gathered from the experiment, I could not fathom why the subjects on average did not choose to play according to the Nash equilibriums. I wished to go in depth of the subjects' choices. Being invited to work with Stein and Matt, has been decisive for choosing experimental economics as the topic for my master thesis.

Stein and Matt: Thank you.

2. Experimental Economics

"Experiment! Make it your motto day and night. Experiment, and it will lead you to the light… If this advice you only employ, the future will offer infinite joy, and merriment… Experiment… And you'll see!"

-Cole Porter

Experimental economics presents the tools needed to among other things empirically test theory predictions. Through experimental economics, it is possible to construct experiments that engage only a small piece of the world, thereby allowing the restriction of effects that might affect the theoretical models (Vernon, 1989).

Vernon L. Smith (1994) identified seven major reasons why economists conduct experiments. He argued that there are more.

"1. Test a theory or discriminate between theories." We can use experiments to compare the predictions and outcomes from different models, to confirm the validity of different theoretical models.

"2. Explore the causes of a theory's failure." When observations are different than theory predictions, one must make sure that it is the predicted failure is due to the failure of theory. If the failure is due to the theory failing, this can help to generate a new and more accurate theory.

"3. Establish empirical regularities as a basis for new theory." For fields that range beyond the constraints of current theory, we can construct experiments to predict outcomes. We may investigate the effects of different incentives programs, different action and so on. The experiment in this thesis investigates the competition between firms.

"4. Compare environments." Comparing environments means to studies the outcome of models with changing the set up of the experiment. How the number of participants, payoffs and asymmetrical knowledge influence the theoretical models.

"5. Compare institutions." Comparing institutions means to study outcomes of different models when everything else is the same (ceteris paribus). An example: with the same subjects and the same incentives (payoffs, knowledge, initial endowments and so on), would

there be a different outcome in an English or a Dutch auction? Experiment could be use to determine which would be the most efficient.

"6. Evaluate policy proposals." Experiments can be used to explore how different policies will affect market efficiency or resource allocation.

"7. The laboratory as a testing ground for institutional design." Laboratories can be used as a testing ground to examine the performance and efficiency of new forms of markets and exchanges.

2.1 Economic experiments distinctive features

Economics first learned the principals of experiments from psychology. Vernon Smith learned some of the techniques from psychologist Sidney Siegel. Since then, experimental economics have developed their own laboratory techniques different than those of cognitive and social psychology (Vernon, 1994).

There are four principal methodological differences (Hertwig & Ortmann, 2001):

1. Script versus open-ended: Economists describe the details of the experiment through written instructions. Psychologists seldom use written instructions.

2. Repeated trails versus one-shot: Economists usually repeat trails to make sure subjects adjust to the environment and understand the task at hand. Psychologists usually just give subjects only one trail at a particular task.

3. Salient pay: Economists usually pay subjects cash to participate in an experiment, where the amount is usually based on the performance of the subject. Psychologists usually do not pay cash, but if they do it is usually a flat fee.

4. Deception: A large fraction of social psychology experiments are based on deceiving the subjects. In economics, deception is considered taboo.

2.2 Nobel prize

In 2002 Daniel Kahneman and Vernon L. Smith received the Nobel Prize in Economics. Daniel Kahneman received it: *"for having integrated insights from psychological research into economics science, especially concerning human judgment and decision-making under uncertainty".* Vernon L. Smith received it: *"for having established laboratory experiments as a tool in empirical economic analysis, especially in the study of alternative market mechanisms".*

3. Anomalies

"Economics can be distinguished from other social sciences by the belief that most (all?) behavior can be explained by assuming that rational agents with stable, well-defined preferences interact in markets that (eventually) clear. An empirical result qualifies as an anomaly if it is difficult to "rationalize" or if implausible assumptions are necessary to explain it within the paradigm."

-Richard H. Thaler

3.1 Endowment effects

The endowment effect is the effect of valuing something that you have been given (initially endowed with) at a higher value than the acquiring value. In "common" tongue it is called sentimental value. Endowment effects are driven not only by subjects' value of an object, but the pain of parting with it (Kahneman, Knetsch, & Thaler, 1991).

Knetsch and Sinder (1984) made an interesting experiment that demonstrates endowment effects. The experiment took place in two undergraduate classes where the students were asked to fill out a questionnaire. The students were immediately given a gift as a "thank you" for participation. One group received a mug, while the other group received a large bar of Swiss chocolate. At the end of the session the students in both classes where given the choice to trade their mugs for chocolate or chocolate for mugs (depending on what gift they were initial endowed with). Approximately 90 percent of the students did not change their gifts. What does economic theory predict will happen in such a market? With transaction cost at an insignificant value, the students should exchange gifts to their most preferred one. Hence the average exchange over the two groups should be approximately 50 percent. If one gift was preferred over the other gift, then they should have observed more exchange in the student group which received the "undesirable" good. With the exchange rate being approximately 90 for both groups, the main effect of endowment is not enhancing the appeal of the good one owns, only the pain of giving it up (Lowenstein & Kahneman, 1991).

Equally a wine collector would not part with an old wine bottle he was endowed with (owned for some time), but would never consider to buy an equal one.

3.2 Status Quo Effect

The status quo effect is the effects that subjects do not wish to deviate from their current state. These effects are usually driven by the "fear" of leaving the current state even if there may be a better choice. With risk involved, the "what if" is the major driving factor here. What if my current choice turns out to be better than the another option (Kahneman, et al., 1991)?

In the 1960's and 1970's there was a TV game show called "Let's Make a Deal". The game show is famous for their "lottery". The participant could choose from one of three doors. Behind one of the doors was a car, which was the valuable prize in the game. Behind the two remaining doors, there were undesirable items referred to as "zorks". For all intents and purposes the "zorks" where worthless. The way this game was played was as follows: first the participant chose a door. This door was not immediately opened. The host would open one of the doors that the participant did not choose and that did not contain the prize. Now the participant was given the choice to switch from her original choice to the other unopened door. If the participant had full information about the game (except where the prize was), should she switch?Two aspects made this game so interesting compared to similar games. First, there was only one real prize. You could either get nothing or take it all. Second, the setup of this game was very different from other comparable games where you were given the option of changing away from you first choice.

This game is easily solved by using Bayes' rule. By this procedure you find that if you switch away from your first chosen door, you double your chances of winning (Page, 1998), (Morgan, Chaganty, Dahiya, & Doviak, 1991).What was stopping the participant form switching to the other unopened door? This game caused a lot of debate even among statisticians, mathematicians and economists. If the scientists can not solve this problem on the spot, how can we expect the participant to do so? When there is uncertainty about what's the dominant strategy, other effects start playing a role. In this case the Status Quo effect will play a major role. Consider these two outcomes. The subject does not switch and loses. Or the subject switches and loses. These two examples have exactly the same outcome: the subject loses. Most people choose not to switch because if you switch and lose that outcome would feel worse than not switching and losing. This will motivate many participants to not switch, even if the probability of winning is lower. This is the driver for the Status Quo effect.

3.3 Loss aversion

Loss aversion implies that the impact of a difference on a dimension is generally greater when that difference is evaluated as a loss than when the same difference is evaluated as a gain (A. Tversky & Kahneman, 1991). Loss or gain is not evaluated at your current endowment (ie. your wealth), just as a momentary loss or gain. Loss aversion can be regarded as feeling a loss as worse than an equal gain. For example, the pain of losing $ 50 feels worse than the joy of finding $ 50.

Loss aversion can be mathematically presented as in equation (1) (Thaler, Tversky, Kahneman, & Schwartz, 1997). In this equation x represents the change in value, be it money or other desirable goods. This is normalized on the current level of endowments. Hence it is a value function rather than a utility function. For gains, the value of *x* is positive. Then x is set in the power of $\alpha \in (0,1)$. This makes the value of gains a concave function. For losses, the value of x is negative. The value function specifies that for negative values of *x* one should use the negative of the negative, hence the absolute values of *x*. This is set in the power of $\beta \in (0,1)$. Which will give us a convex utility function for loses. This value function also has a slope change at the origin presented by $\lambda > 1$.

$$v(x) = \begin{cases} x^{\alpha} & if\ x \geq 0 \\ -\lambda(-x)^{\beta} & if\ x < 0 \end{cases} \qquad (1)$$

Tversky and Kahneman (1992) estimated the parameters of this value function. In their experiment they estimated both α and β to be 0.88 and λ to be 2.25. They conclude that a subject consider a loss to be over twice as bad as an equal gain. But the rate of which a loss or a gain decreases was equal $\alpha = \beta$. Plotting this value function as graph is displayed in Figure 1.

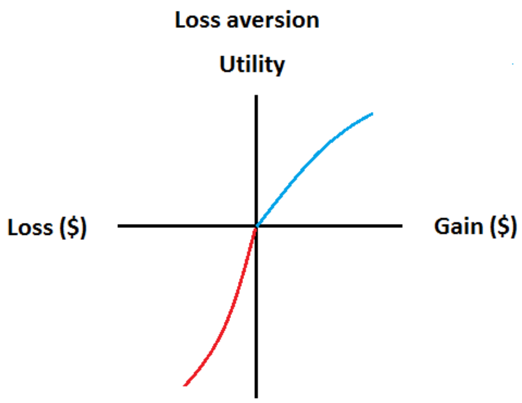

Figure 1: Loss aversion value function. (A. Tversky & Kahneman, 1991)

Figure 1 is a lot steeper on the loss side than the gain side. This breaks with normal utility theory. Normal utility theory assumes positive but diminishing returns of money. A loss or a gain should be valuated as a change in total wealth and not from any normalized reference point. Normal utility theory states that the loss of $ 50 will give a greater absolute change in utility than the equal gain of $ 50. This can be expressed mathematically as in equation (2).

$$U(x) - U(x - \$50) > U(x + \$50) - U(x) \tag{2}$$

Assuming that equation (1) holds for all positive values of x, any agent should have a value function corresponding to figure 2, expressed by a smooth graph without any breaks points, that is concave for all endowment values.

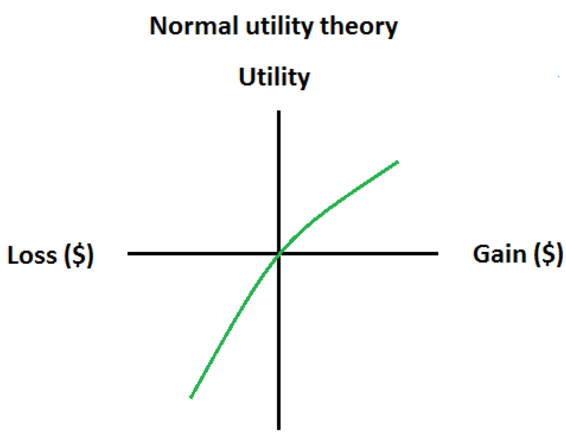

Figure 2: Valuation Gain/Loss in Normal Utility Theory[1]

Loss aversion is driven by agents feeling of defeat and their wish to avoid it. An example on the feeling of loss comes in the next sub chapter (3.4 Framing effects).

3.4 Framing effects

Framing effects refers to decision making problem that occurs when an experiment with expected outcome and probabilities is framed in different ways. Subjects tend to reverse decisions based on perceived of their choices giving losses or gains. Tversky and Kahneman (1981) presented two problems (Figure 3):

Imagine that the U.S. is preparing for the outbreak of an unusual Asian disease, which is expected to kill 600 people. Two alternative programs to combat the disease have been proposed. Assume that the exact scientific estimate of the consequences of the programs are as follows:

Problem 1

Which of the two programs would you favor?

* If Program A is adopted, 400 people will die. (chosen by 22% of participants)

* If Program B is adopted, there is 1/3 probability that no people will die, and 2/3 probability that 600 people will die (chosen by 78% of participants)

Problem 2

Which of the two programs would you favor?

* If Program C is adopted, 200 people will be saved. (chosen by 72% of participants)

* If Program D is adopted, there is 1/3 probability that 600 people will be saved, and 2/3 probability that no people will be saved. (chosen by 28% of participants)

Figure 3: Framing effects. Presented to humans [2]

This hypothetical question was raised in an experiment by Tversky and Kahneman. The experiment was conducted with two different students groups. Their aim was to compare these two different problems, and the ways the students perceived them. We can agree that option A and C are the same, and B and D are the same. As stated in both problems, 600 people are expected to die. If A is adopted then 400 will die, hence 200 will be saved. C is then just A, only that C focuses on the fact that people will be saved and A focuses on the fact that people will died. In the same way B and D are just two sides of the same story. It is interesting to note that problem 1 and 2 are just the reversal of each other. We should expect that subjects would prefer one option either A and C or B and D. However when problem is presented as a loss (i.e. “people will die”), then 78% prefer the risky option. On the contrary, the problem presented as a gain (i.e. “people will be saved”) only 28% preferred the risky option. Tversky and Kahnemans experiment was a hypothetical one.

The drawback of a hypothetical experiment is that the subject’s choices does not have any real consequences. There have been other experiments conducted that have given real payoff to the participating subjects. Interestingly enough this kind of behavior is not just observed in humans, but also observed in monkeys behavior (Lakshminarayanan, Chen, & Santos, 2011). Monkeys where trained to use money (tokens) for which they could buy food. In the first experiment the monkeys could choose to buy food from person A or person B. Person A would receive the monkeys with one piece of apple. If the monkeys bought that piece of apple, they would receive one additional piece of apple. Therefore the monkeys would always receive two pieces of apple with certainty from person A. Alternatively they could buy from person B. Person B would present the monkeys with one piece of apple. If the monkeys would buy from person B, they would receive one piece of apple and with fifty/fifty chance they would receive two additional pieces apple. Therefore the monkeys would with equal probability receive either one piece of apple or three pieces of apple. From person A the monkeys would receive a safe gain and from person B the monkeys would receive a risky gain. This experiment was conducted several times. This allowed monkeys to get used to the transaction with person A and person B. After a while the experiment was changed. Now the monkeys could chooses to buy from person C or D. Person C would present the monkeys with three pieces of apple. If the monkeys would buy from person C, then person C would remove one piece of apple. Therefore the monkeys would always receive two pieces of apple with certainty from person C. Alternatively they could buy from person D. Person D would present the monkeys with three pieces of apple. If the monkeys would buy from person D, then person D would with fifty/fifty chance remove two pieces of apple or not remove any pieces. Therefore the monkeys would with equal probability receive either one piece of apple or three pieces of apple. In these two different experiments option A and C has the same outcome. The monkeys would receive two pieces of apple with certainty. Likewise B and D has the same outcome. The outcome is with fifty/fifty chance to get one or three pieces of apple. As presented in Figure 4.

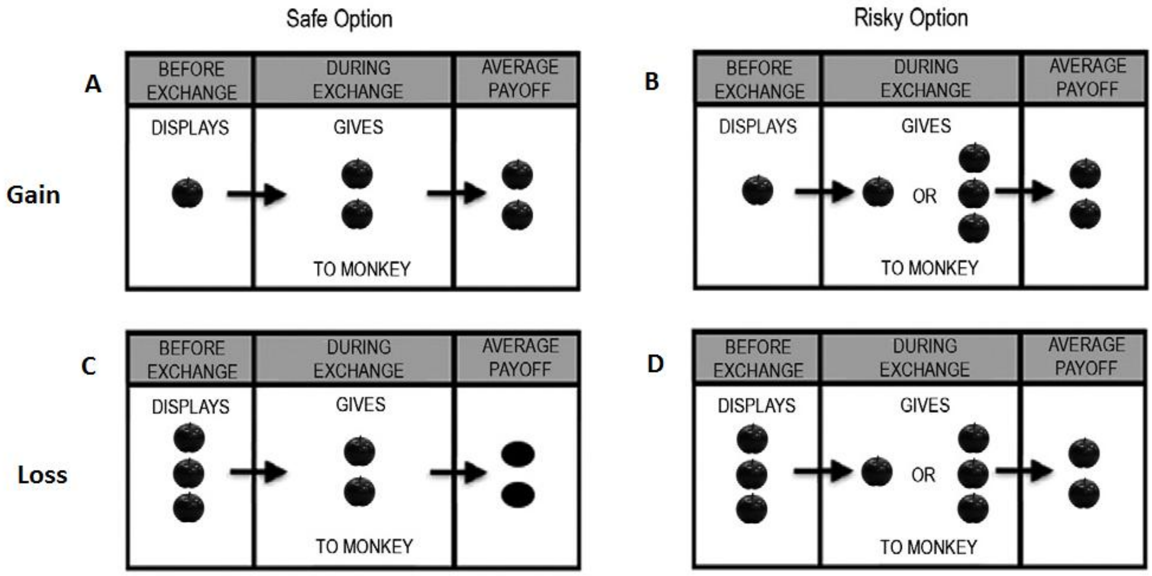

Figure 4: Framing effects. Presented to monkeys [3]

The result of this experiment was that choice D was significantly preferred to C. The monkeys preferred a risk loss to a sure loss. However the monkeys preferred choice A too choice B. Hence the monkeys preferred a safe gain over a risky gain. Humans display the same type of behavior (A. Tversky & Kahneman, 1981). Changing how the experiment was presented changed the choices of the monkeys. When the experiment was presented as gaining additional pieces of apples, the monkeys displayed risk averse behavior. When the experiment was presented as loss of pieces of apples, the monkeys displayed risk loving behavior. It is important to note that this "loss" of apple pieces was pieces of apples the monkeys never received. They where only presented with them when they bought at person C or person D. Rationally when one analyses this game one would assume that if one subjects prefers A over B, then he should prefer C over D and vice versa. There are two effects that play a role here. The first is the framing two different experiments. The two experiments are presented different, but have the same outcome. Subjects perceive two equal experiments as different, even if they are not. Since subjects perceive these experiments as gains and losses the second effect comes in to play, loss aversion. Losses are convex in the amount lost, this leads to the monkeys to try to avoid loss. Since losing two is less than twice as bad as losing one, then the monkeys risk it to try to avoid losing anything. But the framing effect is the dominant anomaly because the monkeys are "losing" something that they are not in possession of. It is only perceived as a loss.

3.5 The Ultimatum Game / Judgment of Fairness

The ultimatum game is frequently referred to by economists. It has its own set anomalies (Thaler, 1988). The most distinct anomaly observed in this experiment is "fairness". Economic models usually do not incorporate fairness, even if fairness seems to be a concept printed in the spine of most humans. The ultimatum game is a two stage, two player bargaining game, where one player (allocator) gets to divide a given sum of money between himself and the other player. The other player (recipient) may accept or reject the offer the allocator proposed. If the recipient accepts, he receives what the allocator offered him and the allocator receives the rest. If the recipient rejects the offer then both players receive nothing. How much should the allocator offer? The Nash prediction is found through backwards induction. The recipient should accept any positive offer. Because the recipient is better off with any positive amount of money than he is with zero. Hence the allocator can give any positive offer and assume that the recipient will accept the offer. The allocator should by these assumptions offer the smallest possible amount of money (epsilon) to the recipient. There is one flaw with this Nash equilibrium. At this equilibrium it only costs the recipient a very small amount of money (epsilon) to reject the allocator's offer. People have a concept of fairness that is not captured in this Nash prediction. Let's dabble a little outside of the equilibrium prediction. The allocator should offer more than epsilon, but how much more? Let's examine some experimental work in this field.

The first experiment conducted in this field (as told by Thaler) was Güth, Schmittberger and Schwarze (1982). They ran an ultimatum experiment with 42 economic students. Half of the where designated as allocator and the other half where designated as recipients. Each allocator received *c* amount of German marks, they were asked to divide the money as they wished between himself and the corresponding recipient. Like a normal ultimatum game, the recipients were given the choice either to accept or decline the allocators' offer. If the recipients rejected the allocators' offer, then both recipients and allocators would receive nothing. If the offer was accepted by the recipients, then the allocator would receive the allotted money subtracted by what he offered the recipient, and the recipient would receive what was offered to him. The mean offer in this experiment was 37% of the allotted money. In 7 of the 21 pairs the allocator offered half of the allotted money. In only two cases did the allocator offer nothing to the recipient, in one of these cases the recipient accepted the zero offer. This experiment invited the subjects back a week later to play the game again. This would give the subjects more time to think about the experiment and “what they should have done”.

In the experiment conducted one week later the mean offer decreased a little from the first experiment, but still a lot higher that the Nash equilibrium. The offers decreased from 37% offered to 32%. 5 of the 21 offers that were rejected. The mean of the rejected offers where about 10%. Both the allocator and the recipients have shown behavior inconsistent with the Nash prediction. It is easy to interpret the actions of the recipients. They were willing to sacrifice an offer of 10% rather then accept an unfair offer. This can be interpreted as the recipients are saying *“take your offer of epsilon and shove it!”*(Thaler, 1988). The allocators could be motivated by two different effects. Firstly the allocators could have a sense of fairness. Secondly the allocators could be worried that the recipient would reject offers that they considered to be unfair.

In another ultimatum experiment by (Kahneman, Knetsch, & Thaler, 1986), they studied if subjects would still behave fair even if the recipient could not decline the offer. The allocator had two different choices to divide $ 20 between him and the recipient. The allocators could take $ 18 and giver their partner $ 2 or split the amount evenly, $ 10 each. Even if the recipient did not have the chance to decline the offer, 76% of the allocators divided the $ 20 evenly. Thereafter, the allocators were organized into two groups: the “fair” ones that split the money evenly and the “unfair” ones that kept $ 18 for themselves. A third group of students were given two options. First option was to take $ 6 themselves and give $ 6 to a random allocator that was designated as “unfair”. The second option was to take $ 5 themselves and give $ 5 to a random allocator that was designated as “fair”. The question is simple, would this subject be willing to sacrifice one dollar to punish one allocator that had been greedy? 74 percent chose to receive one dollar less and split with a “fair” allocator rather than let a greedy allocator receive more money.

3.6 Risk aversion

Risk aversion is the assumption that risk gives in some way disutility. *Hesitation over risky monetary prospects even when they involve an expected gain – will not strike most economists as surprising (Rabin & Thaler, 2001).* Economists can even explain this type of risk aversion with expected utility maximising agents. Consider the follow problem. You may choose option A or option B.

A. You are given $ 50 with certainty.

B. Fifty/fifty chance of receiving $ 100 or receiving nothing.

Which option gives the highest expected utility? Option A is will always give the subject $U(\$\ 50)$. While option B the expected utility is $E(U) = \frac{U(\$\ 100)}{2} + \frac{U(\$\ 0)}{2}$. The utility from $ 0 is zero. Hence the expected utility from option B can be written as $E(U) = \frac{U(\$\ 100)}{2}$.

Utility theory assumes concave utility function. Utility is always positive with more money, but is marginally decreasing. With these assumptions we can conclude that $U(\$\ 50) > U(\$\ 100) - U(\$\ 50)$. Hence $U(\$\ 50) > U(\$\ 100)/2$. This implies that option A gives a higher expected utility than option B, even if they both have the same expected payoff. This is known as risk aversion.

In the example above option A was the best choice for a risk averse agent. A risk neutral agent would be indifferent between the two choices, since risk would not matter to such an agent. If an agent would prefer option B over option A he would be classified as risk loving, hence such an agent would receive utility from risk. The most usual assumption are risk averse agents, as demonstrated in the example above. Violations of this assumption are observed every day. People still buy lottery tickets that have high risk and lower expected payoff than the cost of a lottery ticket. This can hardly be classified as irrational. Rabin and Thaler demonstrate that the concave utility function is quickly violated (Rabin & Thaler, 2001).

Assume that we know that our subject Johnny is a risk averse utility maximising agent. We know that he will always turn down a gamble with fifty/fifty chance of losing $ 10 or winning $ 11. Consider the following problem; Johnny is offered a bet with fifty/fifty chance where he can lose $ 100 or win an amount of $ Y (Rabin & Thaler, 2001).

From the description above, what is the biggest Y such that we know Johnny will turn down a 50-50 lose $100/ win $Y bet?(Rabin & Thaler, 2001).

a) $ 100
b) $ 221
c) $ 2,000
d) $ 20,242

e) $ 1.1 million

f) $ 2.5 billion

g) Johnny will reject the bet no matter what Y is.

h) We can't say without more information about Johnny's utility function.

What would you think Johnny would choose? Rabin and Thaler concluded that Johnny will turn down any bet with 50 percent risk of losing at least $100, no matter how high the upside is. Hence the correct answer is g). Johnny would of course be insane to turn down offers like d, e and f. Why can we conclude that g) is the correct answer? This has to do with Johnny's diminishing return of money. For Johnny to turn down 2.5 billion dollars, it has to be a staggering diminishing return. From the first bet Johnny turned down, we can conclude the following: $U(W+\$11) - U(W) \leq U(W) - U(W-\$10)$. Hence Johnny values a dollar between W and W + $11 by at most 10/11 as much as a dollar between W and W – $ 10. Johnny should turn down the same bet (lose $ 10 / win $ 11) at wealth level W + $21. Hence Johnny values a dollar between W + $11 and W + $21 by at most 10/11 as must as a dollar between W + 21 and W + 32. This leads to valuing the next $ 11 a most 10/11 as much as the previous $ 10. This becomes a converging geometric series. The sum of a convergent geometric series is $\sum_{n=0}^{\infty} x^n = \frac{1}{1-x}\ ,\ |x| < 1$. The sum of infinite numbers of extra $11 hence becomes.

$$\sum_{n=1}^{\infty} \left(\frac{10}{11}\right)^n = -1 + \sum_{n=0}^{\infty} \left(\frac{10}{11}\right)^n = -1 + \frac{1}{1-\frac{10}{11}} = 10 \qquad (3)$$

Equation (3) states that for infinite times of receiving $ 11, Johnny can at most only value infinite money ten times as much as the first $ 11. Hence a loss that is ten times bigger as the loss of the first $ 10, can never be compensated. Such an absurdly high diminishing return of money leads to an absurdly high risk aversion. Rejection of the first bet (lose $ 10 / win $ 11) describes the attitude most people have to risk. Rejection of the second bet (lose $ 100 / win $ ∞) describes nobody.

3.8 Cooperation

Most of micro economic theory and all game theory is based the assumption that people are rational profit maximising agents. In other words, people are selfish and care nothing for the welfare of others. In the classic game "the prisoner's dilemma", economic theory predicts that the subjects should defect. *People are assumed to have no qualm about their failure to do "the right thing"(Dawes & Thaler, 1988).*

This anomaly is often violated. Charitable organizations receive enough money to continue their work. People vote in elections even if it is improbable that a single vote will alter the outcome. Farmers coordinate leaving land fallow, even if a single farmer has incentives to let his herd graze on common lands.

4. Models and Predictions

This chapter is based on the predictions, results and anomalies for a new research and development (R&D) experiment conducted by Østbye, Roelofs and Heen. This theoretical model is based on the same model used in Clark et al (2010), with one major change: firms were given the option to cooperate in R&D, if they wished to do so. This experiment investigated whether or not firms would be willing to cooperate when it is in their best interest to do so (or if they are willing to share R&D even it is not in their best interest to do so). The experiment also investigates how product market competition affects the firms' R&D behavior and how cooperation agreements affect spending R&D.

This experiment was conducted at Western Washington University autumn 2010. One hundred students participated. The preliminary results were presented at the *5th Nordic Conference on Behavioral and Experimental Economics* in Helsinki (12th – 13th November 2010).

4.1 The model

As described by Østbye and Roelofs (2011), the model is based on the interaction between two firms. The two firms compete to enter a product market. The firms must have a successful innovation in order to enter the market. The firms possess some initial knowledge and can increase their knowledge through two means: knowledge sharing or research (investing in R&D). The initial knowledge can be divided equally, representing firms that are on the same technology level. If the initial knowledge is divided unequally then it represents firms that are on different technology levels. For a firm to be successful in innovation, the firm must possess a level of total knowledge that exceeds a threshold which is not known ex-ante. This way, uncertainty is introduced into the model. The threshold which determines success or failure is randomly drawn for a uniform distribution between [0, 1]. Since this number is drawn from zero to one, the level of total knowledge can be interpreted as the probability of success.

The gross profit of firms depends on the type of market formed and the competition intensity. If only one firm is successful in getting an invention, then that firm will capture the whole market by itself, creating a monopoly. Monopoly profit is normalized to 1 (π_m). If a firm is not successful in getting an invention, then that firm will not receive any profits. Hence if both firms are unsuccessful, both receive zero. If both firms are successful in getting an invention they will form a duopoly in the product market. The payoff in the duopoly market (π_d) depends on the competition intensity. Competition intensity in the product market can take one of three forms: *Soft*, *Moderate* or *Tough*. Soft competition corresponds to collusion. In collusion the two firms split the market equally and receive half the monopoly profits each. Hence the profit in a Soft market is 0.5. Tough competition corresponds to Bertrand competition. In Bertrand markets there is no profit for any firm. Hence the profit for Tough competition is zero. In addition to Soft and Moderate there is also a case called moderate with profit of 0.3. The net profit of a firm is the profit receive in the market (whether it be zero or positive) subtracted by the cost of investing in R&D. The relationship between investment in R&D and the knowledge generated from it is for simplification assumed one to one. Investment in R&D will henceforth be referred to as R&D.

Cooperation is introduced by allowing the firms to exchange the knowledge generated by R&D, this will be known as *Sharing*. This model does not incorporate any other binding ways of cooperating. Hence even if the firms cooperate by exchanging knowledge, they still face the same competition in the duopoly market.

Let us now look at the model in more detail. Formalizing the probability of success is given by the cumulative density function:

$$P_i(x_i, x_j) = x_i + \alpha x_j + \mu_i \quad P_i \in [0,1] \tag{4}$$

In equation (4) x_i is R&D and μ_i is initial knowledge for firm *i*. The parameter α represents whether or not the firms exchange knowledge. If the firms do not exchange knowledge, α takes the value 0. Hence firm j's R&D does not affect firm *i*'s probability of success, when there is NO Sharing. If the firms cooperate in R&D α takes the value 1. Hence firm *j*'s R&D increases firm *i*'s probability of success, when there is Sharing. Equation (4) represents the probability of success, hence P_i cannot take a value greater than one. If the sum on the right hand side should sum up to more that one, then P_i is set to one.

Since the randomly drawn threshold is different for the two firms, the probability of success for the two firms is independent from each other. Hence the expected net profit for firms *i* can be written as:

$$E[\pi_i] = \pi_m P_i(1 - P_j) + \pi_d P_i P_j - \frac{x_i{}^2}{2} \tag{5}$$

The first term in equation (5) $\left[\pi_m P_i(1-P_j)\right]$, is the expect net profit from becoming a monopolist. The second term $\left[\pi_d P_i P_j\right]$ is the expected net profit from forming a duopoly (i.e. both are successful in innovation). The last term $\frac{{x_i}^2}{2}$ represents the costs of R&D. The cost of R&D is hence convex in R&D level.

Since the firms face two different randomly drawn thresholds for success, this can lead to the firm with the least knowledge to be successful in innovation and the leading firm to be unsuccessful. It is not always the firm that has conducted the most research in a field that has commercial success.

Substituting equation (4) into equation (5) yields equation (6)

$$E[\pi_i] = (x_i + \mu_i + \alpha x_j)[\pi_m + \left(x_j + \mu_j + \alpha x_i\right)(\pi_d - \pi_m)] - \frac{x_i^2}{2} \tag{6}$$

The first order condition that maximizes expected profit for firm i given firm *j*'s R&D level, gives firm *i*'s best response to firm *j*.

$$\frac{\partial E\pi_i}{\partial x_i} = 0 => \ x_i(x_j) = \frac{\pi_m - x_j\left(1+\alpha^2\right)(\pi_m - \pi_d) - (\mu_j + \alpha\mu_i)(\pi_m - \pi_d)}{1+2\alpha(\pi_m - \pi_d)} \tag{7}$$

From equation (7) we observe the conclusion that the firms R&D are strategic substitutes, since the term $[(1+\alpha^2)(\pi_m - \pi_d)]$ is negative. If firm *j* increases R&D, firm *i* best response would be to reduce R&D. The best response for firm *i* to an increase in firm *j*'s R&D can be written as:

$$\frac{\partial x_i}{\partial x_j} = \frac{-\left(1+\alpha^2\right)(\pi_m - \pi_s)}{1+2\alpha(\pi_m - \pi_s)} < 0 \tag{8}$$

By finding the first derivative of the reaction function equation (7), we need only to examine if the equation is positive or negative. Equation (6) is negative, hence we can mathematically conclude that the firms R&D level are compliments. For no exchange of knowledge ($\alpha = 0$) and for increasing market intensity, both increase how strongly the firms complement each other.

Equation (8) is the best response for firm *i* no firm *j*'s R&D. By swapping *i* and the *j* we get the best response for firm *j* to firm i's R&D. We obtain the equilibrium values of R&D for firm *i* and *j*, by solving for x_i and x_j from the best response functions.

$$x_i = \frac{(\pi_m - (\mu_j + \alpha\mu_i)(\pi_m - \pi_d)(1 + 2\alpha(\pi_m - \pi_d)) - (1+\alpha^2)(\pi_m - \pi_d)\{\pi_m - (\mu_i + \alpha\mu_j)(\pi_m - \pi_d)\}}{(1 + 2\alpha(\pi_m - \pi_d))^2 - [(1+\alpha^2)(\pi_m - \pi_d)]^2} \quad (9)$$

Substituting for the specific parameters values, we obtain the equilibrium values for any of the different cases we consider. The different cases depend on: competition intensity, cooperative agreement and initial knowledge. In this experiment total initial knowledge is 0.2. If total initial knowledge is divided equally then both firms start with 0.1 ($\mu_i, \mu_j = 0.1$). If total knowledge is divided unequally then one firm receives all the total initial knowledge of 0.2 and the other firm receives zero. The firm that receives all total knowledge will be designated the “Leader”, the other firm will be designated the “Laggard”.

See appendix for calculation.

4.2 Predictions

This thesis is about anomalies observed in economics. Deviation from Nash predictions are defined as anomalies. The following sub chapters will describe anomalies that might be observed in the experiment.

4.2.1 Nash equilibrium

Substituting specific values for the parameters used in the experiments in to equation (9), we obtain the Nash equilibrium for each specific case. These equilibria are presented in Table 3 and Table 4. However, there may be other equilibrium concepts that potentially can mitigate the discord between the Nash predictions and data.

4.2.2 Mean risk aversion

In this section a mean variance risk aversion is used to explore another potential equilibrium. Finance portfolio theory assumes that an investor penalizes risk in his portfolio (Bodie, Kane, & Marcus, 2009). If there is no risk aversion, two investments that give the same expected payoff, should be equally as good regardless of risk. This is obviously not a reasonable assumption. An investor needs higher expected payoff to accept risk.In other words, an investor have some disutility from risk. With normal Nash equilibria there is only incorporated expected profit. Assuming that there is some disutility correlated with the variance of payoff, the utility function can be written as:

$$U[\pi] = E[\pi] - A \cdot \sum(\pi_i - E(\pi))^2 p_i \quad (10)$$

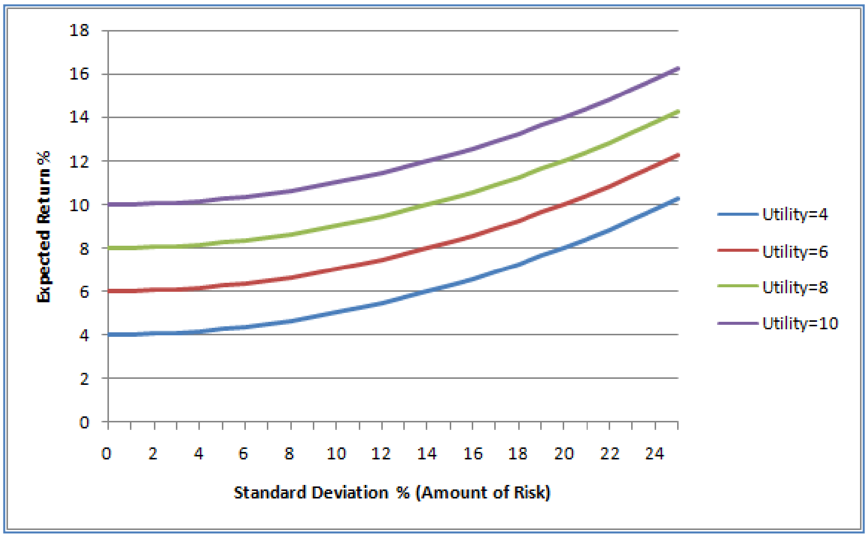

Figure 5: Mean/ risk Utility function[4]

In equation 10 the variable A is a measure of risk aversion. The more risk averse an investor is, the larger the parameter A should be. If the investor is risk neutral then A is equal to zero. Hence the utility function would only be a function of expected payoff. Risk averse investors will have indifference as curves shown in Figure 5. If higher the value of A the more convext the utility curves would be.

There are only three possible outcomes from this R&D game. The variance corresponding to the expected payoff can be found by using the variance for a discrete stochastic variable, given by equation 11.

$$Var(x) = \sum(x_i - E(x))^2 p_i \quad (11)$$

Rewriting this from the formal expression from the R&D investment model, the variance of the payoff can be written as in equation (12):

$$Var\left(\pi(x_i, x_j)\right) = \langle(\pi_m - c(x_i) - E[\pi_i(x_i, x_j)]\rangle^2 P_i(1 - P_j)$$

$$+ \langle(\pi_s - c(x_i) - E[\pi_i(x_i, x_j)]\rangle^2 P_i P_j + \langle(\pi_f - c(x_i) - E[\pi_i(x_i, x_j)]\rangle^2 (1 - P_i) \quad (12)$$

For simplification, we assume that your opponent always plays his Nash equilibrium investment level. Figure 6 and Figure 7 have plotted the expected profit with the corresponding variance. The graphs show what is your expected profit and variance for all level of investment in R&D. These graphs illustrate two cases where the subjects do not share knowledge. The duopoly market payoff is 0.3 (Moderate competition) and initial knowledge is asymmetric at the level 0.2 for the Leader and 0 for the Laggard.

Depending on the firms' preferences they may play Nash or under/over invest. Overinvestment is classified as investing more than the Nash equilibrium and underinvestment is investing less than the Nash equilibrium.

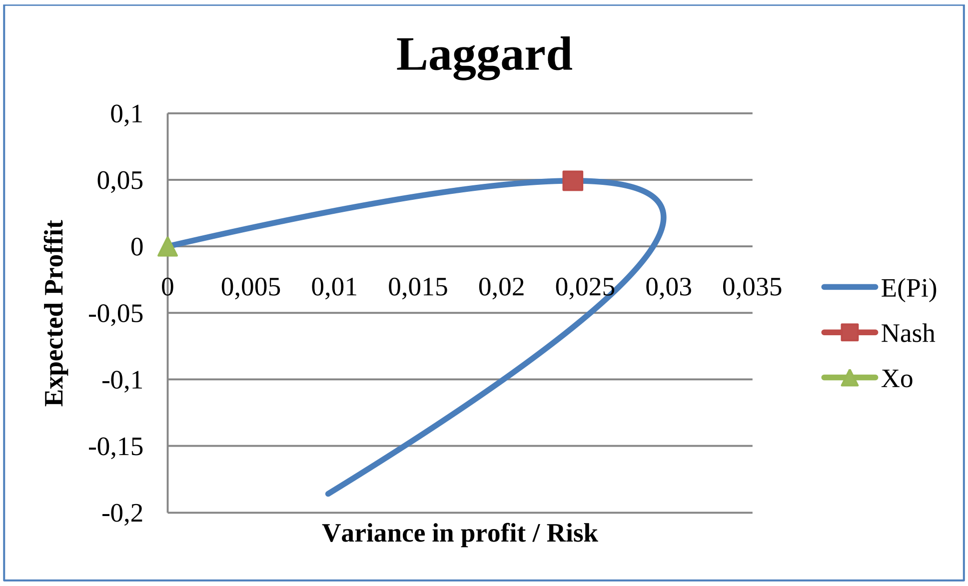

Figure 6: Mean/risk possibility set. Moderate NO Sharing Laggard

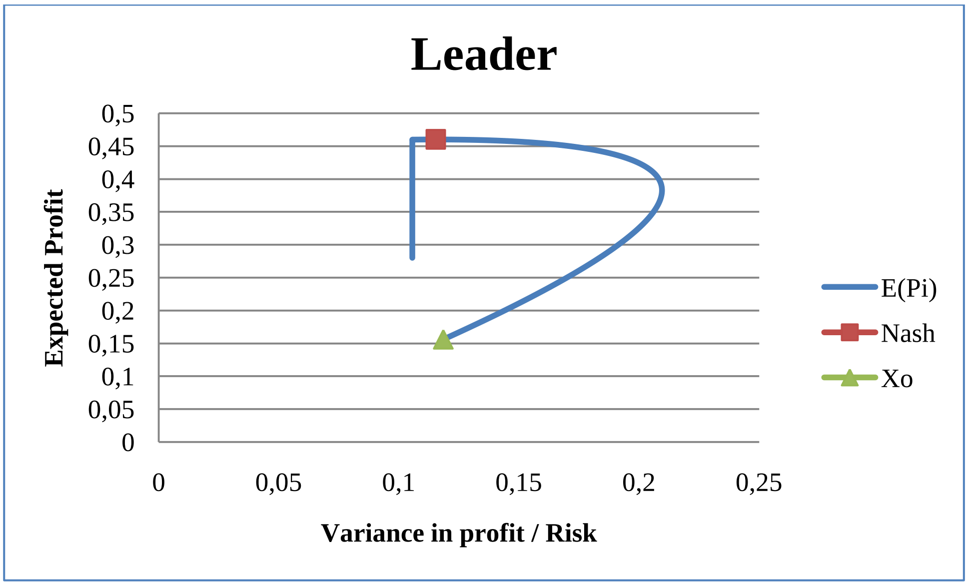

Figure 7: Mean/risk possibility set. Moderate NO Sharing Leader

The graph for E(Pi) gives the loci of expected profit and variance for all levels of investment. The Nash equilibrium is represented by the red square. Since your opponent is assumed to play his Nash equilibrium, you maximize your expected profit by playing your Nash equilibrium. Hence the Nash equilibrium will always be the highest point on the graph. Zero investment in R&D (Xo) is represented by green triangle. Increasing your investment moves you away from Xo. Note that there two-dimensional representation does not display investment in R&D, only the expected profit with the corresponding variance. Both profit and variance are functions of investment.

Let us look at the Laggards' expected profit/risk graph first. Increasing investment from the Xo point, both the expected profit and the risk increase. Both expected profit and the risk increase until the investment level reaches the Nash equilibrium. Continuing increasing investment past the Nash equilibrium increases risk, but reduces expected profit. The conclusion is that every level of R&D over the Nash equilibrium is a dominated strategy. Instead of increasing the investment level of R&D, the firm may rather reduce its investment level. Both increasing and decreasing the investment level reduces the expected payoff, but only decreasing investment also reduces risk. Hence the investment level from zero to the Nash equilibrium dominates the investment levels that are higher than the Nash equilibrium.

Next, let us look at the Leader. From Xo the expected profit and risk increase. But the risk only increases to a certain point. From that point the firms may invest more to increase profit and decrease risk. This is until Nash equilibrium is reached. From the Nash equilibrium investing more decreases both risk and profit. Overinvestment reduces expected profit and risk and underinvestment reduces expected profit and increases risk. Hence overinvesting is the dominant strategy. This analysis has been done for all cases that we will encounter in the later experiment.

For this type of analysis there is no corresponding single equilibrium level for investment. Mean risk aversion is a matter of preference. If the subjects are risk neutral they should play their Nash equilibrium. If they are risk averse, then it is a question of how risk averse they are and what level they would prefer to choose.

This analysis has been done for all cases. The result is given in the Table below. All the mean variance graphs can be found in the appendix.

Table 1: Risk aversion with/without sharing

Sharing		
Competition	Role	Prediction
Moderate	Symmetric	Over invest
Soft	Leader	Over invest
	Laggard	Over invest
Moderate	Leader	Over invest
	Laggard	Over invest
Tough	Leader	Under invest
	Laggard	Under invest

NO Sharing		
Competition	Role	Prediction
Moderate	Symmetric	Under invest
Soft	Leader	Over invest
	Laggard	Over invest
Moderate	Leader	Over invest
	Laggard	Under invest
Tough	Leader	Nash
	Laggard	Nash

In the NO Sharing case for Tough competitions, Nash has been classified as the strategy. This is because that the Nash equilibrium results in the Leader gaining a total knowledge of 1000. This means that the Leader with certainty captures the market. Hence the Laggard should invest 0. If the Laggard invests 0, then the Leader would just lower his expected profit by decreasing investment. Hence Nash would be the least risk and gives maximum profit. The same reason goes for the Laggard, if the Leader invests 800, then the Laggard can not increase expected profit by increasing investment. Hence the Nash would be the least risky and maximum give profit.

4.2.1.1 An alternative approach to: Risk aversion

After limited success with some of the models an alternative approach is used. Your investment can be seen as a lottery where there are only two outcomes of the random draw, you get a failure or you get a success. If you are unsuccessful, you must bear the cost of your investment (much like lottery tickets that did not win). If you were successful you receive the payoff in the market you enter (depending on if you are a monopolist or duopolist and the product market competition intensety in duopoly) and you bear the costs of your investment. In this model I will also introduce diminishing marginal returns, as is used in a normal utility function.

A normal utility function $U(x) = x^a \;\; 0 < a < 1$ breaks down when *x* becomes a negative number. If you are unsuccessful in R&D your profit is negative and a normal utility function will not work. Hence this model will rather look at a change in total wealth rather than momentary gain/loss.

To deal with the problem of the normal utility function not being defined for negative values, every subject was initially endowed with some points. This served as a show up fee for the subjects and as a buffer to avoid the subjects going bankrupt. Hence the subjects have some initial endowment that prevents them from ending up with negative total wealth.

$$E(U(x_i)) = (I + \pi_s(x_i))^\alpha P_s + (I - C_i(x_i))^\alpha (1 - P_s) \tag{13}$$

$$\pi_{s,i}(x_i) = \pi_m\left(1 - P_j\right) + \pi_d P_j - C_i(x_i) \tag{14}$$

$$C_i(x_i) = \frac{x_i^2}{2} \tag{15}$$

In this model π_s is the profit a subject would receive if he/she is successful. The first factor of the first term is the utility of success. Multiplied by the probability of being successful, we have the expected utility of success. The second term is the corresponding expression for expected utility of failure.

Unfortunately this model cannot be solved algebraically. Since each change in wealth term is to the power of α, we can not solve this for a value of *x*. What we can do is numerically analysis. The parameter α is assumed to be $0 < a < 1$. This analysis was preformed in Excel and gave conclusive results of subjects over or underinvestment behavior regardless of choice of *a* and *I*. The only difference observed changing these parameters was the level that should be invested, not a changed between over and underinvestment.

Table 2: Alternative risk aversion

Sharing			NO Sharing		
Competition	Role	Prediction	Competition	Role	Prediction
Moderate	Symmetric	Over invest	Moderate	Symmetric	**Over invest**
Soft	Leader	Over invest	Soft	Leader	Over invest
	Laggard	Over invest		Laggard	Over invest
Moderate	Leader	Over invest	Moderate	Leader	Over invest
	Laggard	Over invest		Laggard	Under invest
Tough	Leader	**Over invest**	Tough	Leader	Nash
	Laggard	**Over invest**		Laggard	Nash

From Table 2 the predictions that have changed has been marked with **bold** script. Those that have not been marked with bold script have the same prediction as the mean risk aversion model.

Why is this risk aversion and not loss aversion? Loss aversion classifieds a loss as worse than an equal gain (chapter 3.3 for a closer description). Risk aversion in chapter 3.6 argues that between a bet of A receiving $ 50 dollars or B receiving with a fifty fifty chance $ 100 or $ 0, subjects would turn down B because B has lower expected utility. Equation (13) determines the expected utility for the new total wealth level.

4.2.2 Cooperation

Another "equilibrium" that might arise is a cooperative "equilibrium". In a cooperative equilibrium subjects maximize joint profit. This means that subjects choose an investment level that is jointly best for both participants in the duopoly. This changes the profit function to become a joint profit function. A joint profit function incorporates both subjects' profit:

$$\Pi(x_1, x_2) = \pi_1 + \pi_2 \tag{16}$$

To maximize this profit function we follow the same procedure as for maximising the normal profit function. We know that we have reached the optimal point when the first derivative is equal to zero. This is an easy equilibrium to simulate numerically in excel. This equation has on weights for how the profit is distributed, it only maximizes the profit in the market.

4.2.3 Equilibrium

For expository purpose all numbers are multiplied by 1000. This has also been done for the subjects participating in the experiment. Choosing to invest 300 seems a lot more intuitive than choosing 0.3.

Table 3: Predicted equilibrium for Sharing

Competition	Role	R&D		Profit		
		Nash	Coop	Nash	Coop	n
Moderate	Symmetric	226	260	313	317	188
Soft	Leader	300	360	515	524	70
	Laggard	300	360	315	324	70
Moderate	Leader	226	260	420	424	61
	Laggard	226	260	220	224	61
Tough	Leader	162	180	341	342	45
	Laggard	162	180	141	142	45

Table 4: Predicted equilibrium for NO Sharing

Competition	Role	R&D		Profit		
		Nash	Coop	Nash	Coop	n
Moderate	Symmetric	547	900/0*	204	525 / 30	132
Soft	Leader	733	800	416	680	90
	Laggard	533	0	142	0	90
Moderate	Leader	780	800	461	680	99
	Laggard	314	0	49	0	99
Tough	Leader	800	800	670	680	115
	Laggard	0	0	0	0	115

* The cooperative equilibrium for symmetric moderate is that one invests 900 and the other zero.

The cooperation equilibrium for the NO sharing cases, is the Laggard investing nothing and the Leader taking it all. This hardly seems fair, but it is the investment level that maximizes joint profit. The Laggards expected profit is low compared to the expected profit for the Leaders. One might think that Laggard should just think "I'll just not invest this round and not have any cost of R&D and let my opponent take it all". The symmetric cooperative solution is that one player invests 900 and the other 0. Since the subject has no way of communication this is an equilibrium that will be impossible to coordinate upon. Hence cooperation on R&D level will most likely not be observed for NO sharing cases.

4.2.4 Dominant strategies

Since the subjects have the option to sharing knowledge , there will be a dominating strategies with the sharing of investment in R&D or not sharing of investment in R&D. Comparing the expected profit for the subjects with regards to sharing or no sharing, will reveal what strategy maximizes subjects expected profit. A Leader in a Soft market is predicted to receive 515 if he shares knowledge and is predicted to receive 416 if he does not share knowledge. For this treatment sharing knowledge is the dominant strategy. In Table 5.2.4x finding the dominant strategy has been done for all cases.

Table 5: Sharing dominant strategy

Competition	Role	Dominant strategy
Moderate	Symmetric	Share
Soft	Leader	Share
	Laggard	Share
Moderate	Leader	**Not** Share
	Laggard	Share
Tough	Leader	**Not** Share
	Laggard	Share

Leader in the treatment for asymmetric Moderate and Tough markets are the only cases where firms have no incentive to share knowledge. Since the Leader does not have any incentives to share knowledge then there should not been any knowledge sharing in Moderate and Tough asymmetric markets. For the Moderate treatment the total amount of profit in a Sharing market is higher than in a No Sharing one. A side payment from the Laggard firm could lead to a pareto improvement. The side payment treatment is not incorporated in to this theses. This is in accordance with the Nash equilibrium predictions. Table 6 shows the mean profit in the experiment conducted by Clark, Østbye and Roelofs in 2010. From the Table one can see that the mean profit in all the sharing sessions gave higher profit than, any session where there was no sharing. Leader in Moderate and Tough markets should theoretically do better by not sharing, but the empirical evidence show that they received higher mean profit by sharing knowledge.

Table 6: Profit in with Sharing and NO Sharing

Competition	Role	Mean Profit	
		No sharing	Sharing
Moderate	Symetric	215	301
Soft	Leader	314	497
	Laggard	95	273
Moderate	Leader	291	396
	Laggard	68	201
Tough	Leader	297	409
	Laggard	5	145

With this contradicting information the question becomes: “What is the Leader’s best choice?” This is not easy to answer ex-ante. This question will be explored in some detail in the result section.

As stated, a side payment from the Laggard firm could lead to a pareto improvement. To prove this, consider the asymmetric Moderate treatment. For the sharing cases the expected profit for the Leader firms are 420 and 220 for the Laggard firms. For the no sharing cases the expected profit for Leader firms are 461 and 49 for the Laggard firm. The total profit in the sharing case is 640, but only 510 for the no sharing case. Assuming that the firms’ chooses their Nash equilibrium level of investment, the Laggard firm should be willing to pay the Leading firm at maximum 171 for the Leading firm to share knowledge. To accept knowledge sharing, the least amount the Leader firm should be willing to accept is 41. Since the least willingness to accept is smaller than the maximum willingness to pay, there should be sharing in markets that have side payments (like the real world).

4.2.5 Loss aversion

To use the Tversky and Kahneman (1991) definition of loss aversion for this experiment would prove difficult. After conversation with some of the students that participated in the experiment, one of them stated: “The worst ting was to not get a success” (ie. not being successful in R&D). Loss aversion in the simplest form can be explained as the feeling of defeat being the worst thing. Testing for loss aversion in this experiment will be done by assuming that there is some value of disutility associated with loss (i.e. not being successful in R&D).

$$E[U(x_1, x_2)] = \pi_m P_1(1 - P_2) + \pi_d P_1 P_2 - \pi_f(1 - P_1) - \frac{{x_1}^2}{2} \tag{17}$$

In equation (17) π_f has been added to the expected profit function. The payoff for failure has through the model been zero. This section assumes that π_f has some negative values that relates to subjects disutility with loss. Hence equation (17) becomes a utility function rather than an expected profit function.

A utility maximizing agent maximizes his utility in the same way a profit maximizes profit.

$$\frac{\partial E[U(x_1,x_2)]}{\partial x_1} = \pi_m - P_2(\pi_m - \pi_d) - \alpha(\pi_m - \pi_d)P_1 - x_1 + \pi_f = 0 \tag{18}$$

Solving equation (18) for π_f, we get.

$$\pi_f = -\pi_m + P_2(\pi_m - \pi_d) + \alpha P_1(\pi_m - \pi_d) + x_1 \qquad (19)$$

The monetary loss of failure will be found based on the average investment of subjects. Hence π_f can only be found after conduction the experiment, π_f will be estimated based on empirical results.

4.2.6 Team players and Induvidualist

One hypothesis this experiment wishes to investigate if certain players can be classified as more cooperative than others. This model incorporates endogenous sharing. Hence I wish to tests the difference between the sharing decision and the investment decision. This will be done by separating the subjects by the frequency of offering to exchange knowledge with their counterpart. If players on average more often try to exchange knowledge with their counterpart, will they also choose a more cooperative investment level? We form a simple division. The first group is designated "Team player", these are the subjects that most frequently offered to form cooperation in R&D. The second group is designated "Individualist", they are the subjects that less frequent offer to form cooperation in R&D.

4.3 The Experiment

This experiment was conducted at Western Washington University in the fall of 2010. One hundred undergraduate students from introductory economics courses were recruited to participate. The students were divided into ten different groups, with ten students in each group. The experiment had five different types of treatment. Each treatment was run two times, with two different groups of students. The objective of the experiment was to observe the willingness for Leaders to cooperate with Laggards. Therefore only one symmetric treatment was conducted, to get a reference case that other cases can be compared against. In this master thesis, data for four of the five treatments will be used.

4.3.1 Experimental Design

There was a total of 16 periods in each experimental session. In each period the subjects were first asked if they wished to exchange R&D with their counterpart. The cooperation result of the first stage was immediately revealed. In the second stage the subjects were asked to make an investment decision from 0 to 1000. The amount of investment (R&D) was added to any endowment of initial knowledge and any knowledge gained through knowledge exchange, to determine the subject's total knowledge.

To determine success or failure in investment, uniformly distributed random number was drawn [0, 1000]. A firm projects was successful if the total knowledge of the firm was greater than this random number. The firms faced different random drawn numbers. In the last stage the subjects were presented the result screen, informing the subjects of the resulting profit.

In each period subjects were randomly paired with one other subject. The subjects were quasi randomly assigned to be Leader or Laggard. This was only quasi-random for two reasons. First of all, it was to make sure that every subject were equal numbers of times, Leader or Laggard. Second, it was to avoid that any subjects were Leader or Laggard too many times in a row. Subjects were informed in the first stage about the market intensity and whether they were a Leader or a Laggard.

We presented the subjects to five different treatments. All of these were conducted twice.

Table 7: Treatment types

	Market	Endowments
Treatment 1	Moderate	Symmetric
Treatment 2	Soft	Asymmetric
Treatment 3	Moderate	Asymmetric
Treatment 4	Tough	Asymmetric
Treatment 5*	Moderate	Asymmetric

(* Treatment 5 added a side payment for knowledge sharing)

In Treatment 1 subjects had symmetric initial endowment of. This treatment served as a benchmark. Treatments 2-3 were asymmetric treatments with each one having one of the different market intensity. Treatment 5 had a side payment connected with cooperating in R&D. The Laggard had to pay 100 to the Leader to exchange knowledge. Both the Leader and the Laggard had to agree to exchange knowledge before there would be any exchange. This treatment was not included in this thesis.

This economic experiment was programmed in Z-tree (Fischbacher, 2007). Z-tree is a ready-made toolbox for conducting economic experiments. The experiment was presented in such as way that the subjects had all the information they needed to reach their decisions. The game was presented in several stages. The information and options available to the subjects will be presented and gone through in detail below.

Equal information in all stages

To avoid some confusion it is important to note that in this master thesis exchange of knowledge has been referred to as Sharing and cooperation will be referred to as choosing a joint profit maximizing R&D level. In the experiment Sharing or NO Sharing was reported as "cooperation status", this refers to the exchange of knowledge. All stages have some common factors. Every stage showed the current period, the total number of periods and the time remaining in that stage. Every stage also informed the subjects about all endowments. The endowments tab showed: Payoff in the duopoly market, payoff in monopoly market, firms initial knowledge (yours and your opponent) and cooperation status. Cooperation status is not shown in the first stage for the obvious reason that this is where firms choose to cooperate or not. The firms are also given the information about how much in total profit they have. This information was presented in every stage.

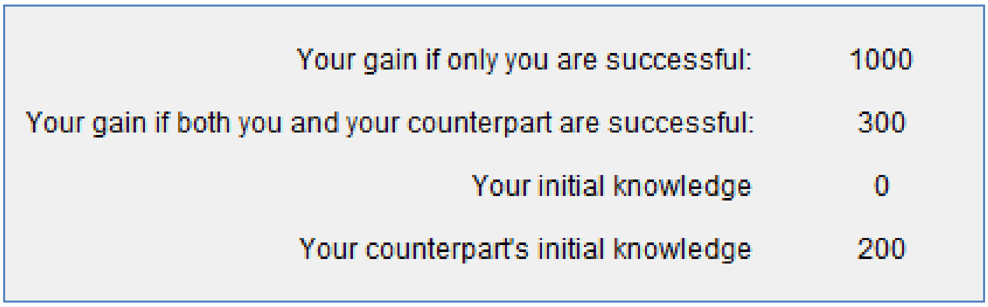

Figure 8: From the experiment: Endowments tab in the cooperation stage.

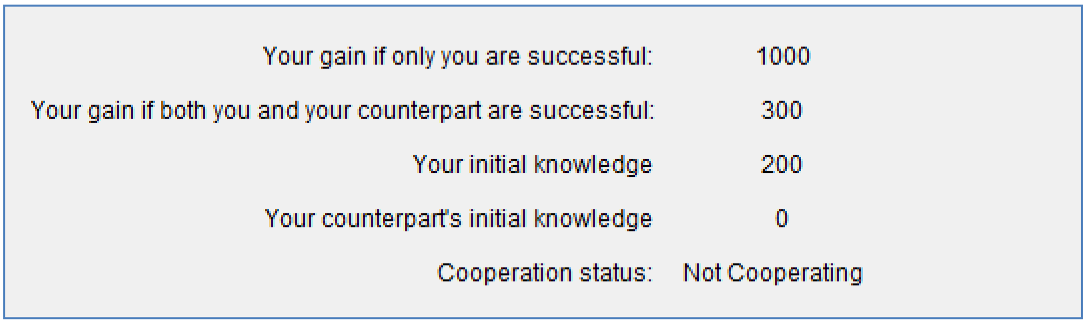

Figure 9: From the experiment: Endowments tab in the investment and result stage.

Sharing stage

In the sharing stage the firms were given the option to share all R&D generated through investment in R&D. This could only lead to symmetric cases. Both have to say "Yes" to cooperation for there to be cooperation. If one subject (or both) said “No” then neither of the two would share their knowledge. The question in this stage states “provided they share”, this is added to avoid a “Prisoners dilemma” situation. For everyone would surely be better off if your counterpart would give him all his knowledge and you would not have to return any.

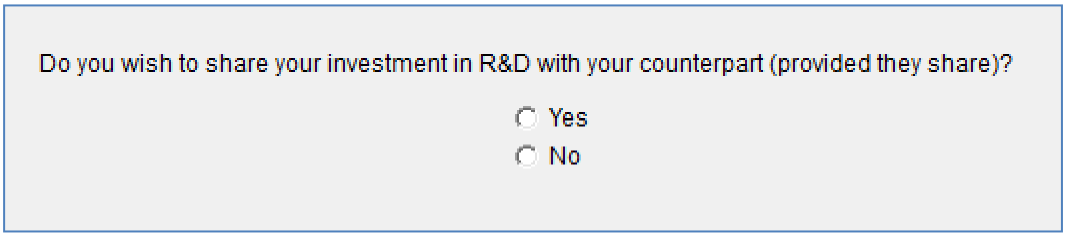

Figure 10: From the experiment: Sharing alternative.

Investment stage

In the investment stage the firms were asked to choose a level of investment. The subjects choose their level of investment simultaneously so they do not know what level the counterpart will choose. The cost of investment increases at a quadratic rate. The cost of investment was also given in this stage, with the cost of investment for every hundred increment of investment level.

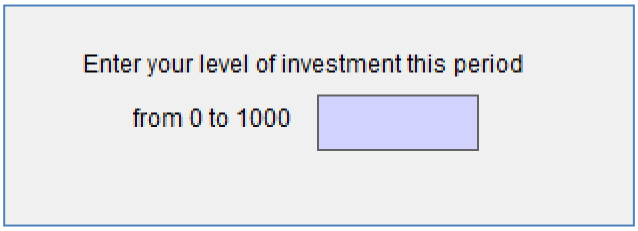

Figure 11: From the experiment: Investment Level.

Product market/result stage

The product market stage is in this experiment is also called the result stage. This is because in this stage the firms/subjects only get the result from the previous stages. This stage displays whether or not they have succeeded in R&D and whether or not their counterpart has succeeded. The subjects would also be informed about their total knowledge, the random draw and their counterparts’ R&D. This stage also informed the subjects about their payoff, cost and net profit.

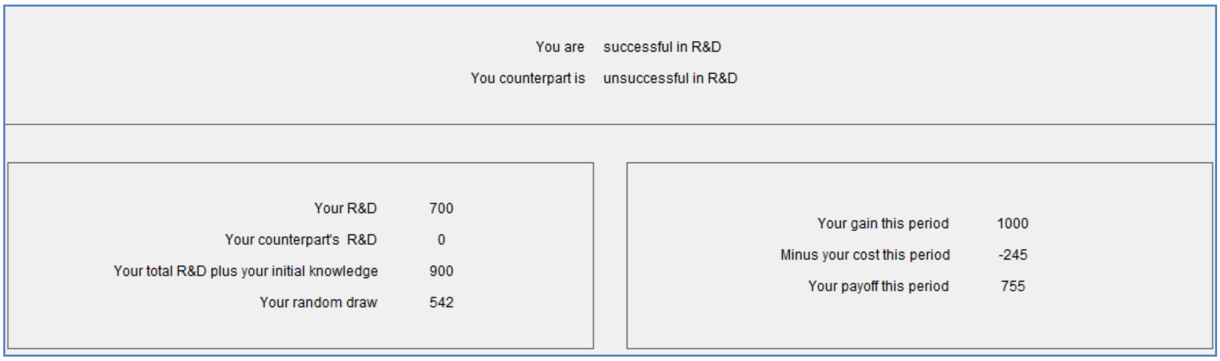

Figure 12: From the experiment: Result payoff

The appendix has a print out of every stage. Show the complete picture the subject got to see in every stage.

4.4 Hypothesis

H. 1. Subjects that exchange knowledge will implicitly cooperate on the R&D level.

H. 2. Subjects behave risk averse.

H. 3. Subjects behave loss averse.

H. 4. Subjects that on average more frequently try to form cooperation with their counterpart will choose a more cooperative level of R&D.

5 Results

The experiment generated (for the treatments considered in this thesis) 2560 observations, 1280 were investment decision and 1280 were knowledge sharing request. These came from 10 subjects over 16 periods in four different treatments, were all treatments were conducted twice. The statistical test that is used is a standard t-test. It could be argued that a more robust non-parametric test should be use here. However since t-tests are familiar to a wide audience, a non-parametric test is left for future work.

5.1 Summary Statistics

The experiment generated 540 observations of subjects choosing to share knowledge and 740 observations of subjects not share knowledge. The Nash predictions and the mean observations, with standard deviations in parentheses, are summarized in Table 8 and 9.

The analysis for the cases where subjects shared knowledge is summarized in Table 8. The model predicted investment levels below actually observed investment level. In every case the subjects overinvested compared to the Nash prediction. The subject overinvested regardless of market competition or initial endowment.

With regard to profit, the actual profit is lower then the predicted profit, in all cases. The Subjects in the Moderate Symmetric case overinvested, but received a profit fairly close to the predicted value. The Laggards in Tough are the real losers for this group, earning almost 200 less then the predicted value, they are also the only ones that receives a negative profit (earning -58 with the prediction of 141).

Table 8: Results Sharing

Market	Position	R&D		Profit		
		Nash	Mean (sd)	Nash	Mean (sd)	n
Moderate	Symmetric	226	341 (124)	313	308 (350)	188
Soft	Leader	300	337 (187)	515	483 (327)	70
	Laggard	300	416 (152)	315	287 (297)	70
Moderate	Leader	226	255 (198)	420	343 (396)	61
	Laggard	226	365 (201)	220	161 (313)	61
Tough	Leader	162	256 (217)	341	233 (469)	45
	Laggard	162	276 (205)	141	-58 (78)	45

Continue with the subjects that did not share knowledge (Table 9). With symmetric initial endowments and Moderate market competition, the mean investment in this case was very close to the Nash prediction (557 with a prediction of 547). Even with the mean investment close to the Nash prediction the mean profit fell surprisingly short to the predicted profit (152 with a prediction of 204). For the cases of Leader in the market competition of Soft, Moderate and Tough (all the cases) there were underinvestment compared to the Nash prediction (575 with prediction 733 for Soft) (530 with prediction 780 for Moderate) (542 with prediction 800 for Tough). On the contrary the Laggards overinvested for all the cases (Soft, Moderate and Tough) (600 with prediction 533 for Soft) (488 with prediction 314 for Moderate) (435 with prediction 0 for Tough).

Table 9: Results NO Sharing

Market	Position	R&D		Profit		
		Nash	Mean (sd)	Nash	Mean (sd)	n
Moderate	Symmetric	547	557 (175)	204	152 (379)	132
Soft	Leader	733	575 (227)	416	276 (369)	90
	Laggard	533	600 (274)	142	149 (337)	90
Moderate	Leader	780	530 (216)	461	256 (409)	99
	Laggard	314	488 (248)	49	107 (349)	99
Tough	Leader	800	542 (169)	670	213 (478)	115
	Laggard	0	435 (275)	0	-2 (329)	115

With regard to the decision of sharing knowledge, there was some deviation from the predictions. The Nash prediction of dominant strategies told us that there should be sharing of knowledge in the symmetric Moderate treatment and asymmetric Soft treatment. Following, there should be no sharing for the asymmetric Moderate and Tough treatment. The only treatment, were subjects agreed to share knowledge more often then not, was the symmetric Moderate treatment (188 shared and 132 did not share). For all the asymmetric treatments the subjects did share less often than not (140 shared and 180 did not share for Soft) (122 shared and 198 did not share for Moderate) (90 shared 230 did not share for Tough).

The asymmetric Soft treatment was the only treatment where the subjects did the opposite from the predicted behavior – even the Nash prediction predicted that subjects should share knowledge. This seems to indicate that when there is asymmetric sharing of initial knowledge, then the Leaders do not wish to give away their advantage, even if they benefited from doing so. This was one of the questions we asked in the introduction to chapter 4.

Looking back at the results of the experiment, based on the average profit, would the subjects be better off sharing knowledge or not to share knowledge? In the Symmetric Moderate treatment the average profit for subjects when sharing was 308 and when not sharing 152. On average the subjects would make twice as much profit from sharing than not sharing knowledge. The Nash equilibrium also concludes that the dominant strategy would be to share knowledge.

In theory and the empirical results, Sharing is the dominant strategy. In the asymmetric Soft treatment the average profit for the subjects when sharing was 483 for Leaders and 287 for Laggards, compared to not sharing was 276 for Leaders and 149 for Laggards. On average the Leaders and the Laggards would make nearly twice as much if he shared knowledge. For the asymmetric Soft treatment the dominant strategy and the high average pay off were both through sharing knowledge. For the asymmetric Moderate treatment the average profit for the subjects when sharing was 343 for Leaders and 161 for Laggards, when not sharing was 256 for Leaders and 107 for Laggards.

Again, both Leader and Laggard would be better of by sharing knowledge, Nash tells us the opposite. In the end more subjects wished not to share knowledge, even if they should have been better of by doing so. For the asymmetric Tough treatment the average profit for the subjects when sharing was 233 for Leaders and -58 for Laggards, when not sharing 213 for Leaders and -2 for Laggards. For this treatment the Leader would be a little better off by sharing, but the Laggard would be a lot worse off by sharing.

Ironically enough this is the reverse of the Nash predictions. The Leader should have done better by not sharing, but did better by sharing and the Laggard should have done better by sharing but did worse by sharing. In the end the Laggards and theory was against sharing, leading to not sharing being the most preferred strategy.

In all cases in the experiment the Laggards overinvest. Laggards also overinvest more than Leaders.

5.1. Team player and Individualist behavior.

This section will continue the assumption raised in section 4.2.6 (Team players and Individualists). Subjects in every treatment are split into two groups, the Team player and the Individualist. The reason for splitting into these two groups is to test if there is a difference of the mean investment between these two groups. The assumption is that mean of the Individualist subjects is different than for the Team player, hence a two-tail t-test is used. First I will analyze the cases where the subjects share knowledge. The p-value tells us on what significance level we can reject the null hypothesis that the means are equal.

Table 10: Results: Team player and Individualist in Sharing

Competition	Role	Mean investment (sd)		
		Team player	Individualist	p-value
Moderate	Symmetric	327 (102)	371 (162)	0,070
Soft	Leader	299 (163)	426 (209)	0,019**
	Laggard	370 (131)	466 (159)	0,008**
Moderate	Leader	209 (142)	314 (243)	0,053
	Laggard	319 (152)	430 (243)	0,048*
Tough	Leader	239 (170)	283 (278)	0,559
	Laggard	250 (186)	301 (224)	0,418

** Significant at the 1% level. * Significant at the 5% level.

From Table 10 we can draw a few conclusions. For all treatments investments are strategic substitutes. From Table 10 the mean investment for Team player subjects is lower than for the Individualist subjects. For soft cases, the difference in means was significant at the 1% level. The Team player subjects seem to be less aggressive in investment, choosing an investment level that is more cooperative than the Individualist subjects. The moderate symmetric case fails to become statistical significant. In the asymmetric cases for moderate competition, the difference in means were significant for Laggards at the 5% level, the Leader fails just barely to become significant. From the cases of asymmetric Soft and Moderate the most significant data is for the Laggards.

This is not necessary surprising, since the Laggards have the most to gain from sharing knowledge. The best way to get Leaders to wish to share knowledge in the future is choose an investment level that is good for both, so that Leaders in the future will be willing to share. The Tough cases were quite different. There were no significant difference between the Team player and the Individualist. Tough times do not seem to bring out the best in people. When competition gets harder the Team player becomes more and more like the Individualist.

Table 11: Results: Team player and Individualist in NO Sharing

Competition	Role	Mean investment (sd)		
		Team player	Individualist	p-value
Moderate	Symmetric	531 (134)	576 (201)	0,126
Soft	Leader	573 (176)	575 (260)	0,958
	Laggard	563 (261)	647 (286)	0,157
Moderate	Leader	433 (190)	588 (210)	0,0003**
	Laggard	437 (272)	517 (229)	0,139
Tough	Leader	561 (196)	533 (156)	0,455
	Laggard	404 (248)	452 (290)	0,347

** Significant at the 1% level.

Without sharing the story is quite different. Drawing any common conclusion is a lot harder than when subjects share knowledge. Testing for the difference of two means all but one was not significant at even the 10% level. The only significant difference that could be found was the Leaders in the Moderate case. Under Tough there is no statistical difference between Team player and Individualist subjects. For Leaders in Soft market there is no statistical difference between the Individualist and the Team players. They are actually surprisingly equal (they are equal at a 5% significant level!). The Individualists are the subjects that the most frequently try to form sharing. If a Team player Leader was rejected to exchange knowledge with a Laggard (knowledge sharing is a lot better for the Laggard), would the Team player really continue to be altruistic? This can be seen as the Team player Leader punishing the Laggard for not sharing knowledge.

5.2 Risk aversion

Risk aversion is often discounted as an anomaly (Rabin & Thaler, 2001). Anomaly or not, can it be used to explain the actions of the subjects in the experiment? Table 12 presents reviled preferences based on the cases of sharing of knowledge and Table 13 contains the cases for no sharing of knowledge. In these Tables the Prediction tells us what strategy a risk averse agent would choose.

For the Sharing cases; the risk aversion model predicts that for symmetric/asymmetric Moderate market and the asymmetric Soft market subjects should overinvest, and in the asymmetric Tough market should underinvest. The observation from all the sharing cases was overinvestment. Hence we observe consistent with risk averse behavior for all but the asymmetric Tough cases. Risk loving will be discussed below.

Table 12: Results: Risk aversion in Sharing

Market	Position	R&D		Risk aversion	
		Nash	Mean (sd)	Prediction	Reviled preference
Moderate	Symmetric	226	341 (124)	Over invest	Risk averse
Soft	Leader	300	337 (187)	Over invest	Risk averse
	Laggard	300	416 (152)	Over invest	Risk averse
Moderate	Leader	226	255 (198)	Over invest	Risk averse
	Laggard	226	365 (201)	Over invest	Risk averse
Tough	Leader	162	256 (217)	Under invest	Risk loving
	Laggard	162	276 (205)	Under invest	Risk loving

For the no sharing cases, the model preformed considerably worse than for sharing. The model had only one correct prediction (Laggards in Soft). The symmetric moderate case preformed fairly well. Since the mean investment is close to the Nash prediction, the subjects are risk neutral and indistinguishable from to weak risk aversion (and risk loving).

Table 13: Results: Risk aversion in NO Sharing

Market	Position	R&D		Risk aversion	
		Nash	Mean (sd)	Prediction	Reviled preference
Moderate	Symmetric	547	557 (175)	Under invest	Risk neutral
Soft	Leader	733	575 (227)	Over invest	Risk loving
	Laggard	533	600 (274)	Over invest	Risk averse
Moderate	Leader	780	530 (216)	Over invest	Risk loving
	Laggard	314	488 (248)	Under invest	Risk loving
Tough	Leader	800	542 (169)	Nash	Risk loving
	Laggard	0	435 (275)	Nash	Risk loving

For the cases were the benchmark predicted underinvestment the model predicted poorly. That a risk averse subject should underinvest seems counter intuitive. Only through in depth analysis can we conclude that a subject should underinvest to reduce risk. But it does not reduce the variance of the profit.

Unfortunately risk aversion did not offer a good explanation for the subject's behavior. As a matter of fact, the model only predicted correctly in 6 out of 14 cases. This model is based on the assumption that your opponent chooses his Nash equilibrium. For the subjects the risk (variance in profit) and expected profit associated with R&D would be hard to predict.

Because of this the subjects probably did not realize the effects of all their actions. Another effect is the risk the subjects faces that their opponent does not play Nash R&D. If your opponent does not play their Nash equilibrium, then the risk profile of your investment in R&D changes. This analysis has not taken this into account because of the share complexity of the problem. This problem will be left for future analysis.[5]

5.2.1 Alternative risk aversion

This section follows the same argument as the chapter above (chapter 6.2) using the alternative risk aversion model. The only difference with the alternative explanation model is that it predicted overinvestment for Leader and Laggards in the Tough sharing cases and for Symmetric NO Sharing cases. Since risk aversion has been gone through in detail in chapter 5.2 it will not be reviewed here.

Table 14: Result: Alternative risk aversion

Sharing			
Competition	Role	Risk aversion Prediction	Follwed
Moderate	Symmetric	Over invest	Yes
Soft	Leader	Over invest	Yes
	Laggard	Over invest	Yes
Moderate	Leader	Over invest	Yes
	Laggard	Over invest	Yes
Tough	Leader	Over invest	Yes
	Laggard	Over invest	Yes

No Sharing			
Competition	Role	Risk aversion Prediction	Follwed
Moderate	Symmetric	Over invest	Yes
Soft	Leader	Over invest	No
	Laggard	Over invest	Yes
Moderate	Leader	Over invest	No
	Laggard	Under invest	No
Tough	Leader	Nash	No
	Laggard	Nash	No

Table 14 displays the prediction of risk aversion and if they subjects followed the predictions. The alternative risk aversion model has three more correct predictions than the other risk aversion model, 9 of 14 correct. All correct for the Sharing cases.

5.3 Loss aversion

This section is closely linked to subjects' over- or underinvestment. Hence I will refer to the Table in section 6.2 to reveal who over- or underinvest. The loss aversion model is build so if π_f is positive, and then subjects would be classified as loss averse. If π_f is negative, then the subjects are "loss lovers". Equation (19) in 4.2.5 has been used to calculate the monetary loss of failure. Firstly I will go through the cases for knowledge sharing. Based the on the average investment of sharers in the Symmetric Moderate market, they would have to feel that being unsuccessful was equal to losing 435. Since the subjects overinvested, this would reduce their expected profit but increase their chance of success. From Table 15 we observe that all the values of feeling of loss are positive. All the subjects in the sharing cases can be classified as loss averse. From Table 15 we observe two relations. Firstly, the subjects become more loss averse as market competition intensifies. Why this is the case is not immediately clear because when competition intensifies, there is less shared payoff in the product market. The Laggard is more loss averse than the Leader. All Laggards in the sharing cases overinvest more then the Leader. Presumably the Laggard feels that he is behind and must invest more to compete. Hence the Laggard would consider failure worse than the Leader.

Table 15: Results: Loss aversion in Sharing

Competition	Role	Feeling of loss
Moderate	Symmetric	435
Soft	Leader	190
	Laggard	269
Moderate	Leader	263
	Laggard	373
Tough	Leader	520
	Laggard	540

The values in Table 15 are lower for all cases than the values in Table 16. The valuating of loss in the Symmetric Moderate case is only 16. This is very low compared to any monetary loss in the sharing cases. Since the subjects invested close to their Nash equilibrium this is consistent with a low valuation of loss. Hence loss aversion does not seem to play a major role in the Symmetric Moderate market.

The asymmetric cases are different. Before interpreting these results for loss aversion in the asymmetric NO sharing cases, a quick review of the results of the experiment is needed (Table 9). For every type of market in NO Sharing the Leader underinvested and the Laggard overinvested. The best response for a Laggard is to overinvest if the Leader underinvests. Since the monetary value of loss for the Laggard in Soft and Moderate is close to zero, the Laggard chooses the Nash best response to the Leaders level of R&D. The Leader on the other hand would have to be classified as “loss lovers”. Being a “loss lover” is irrational. So why use this classification?

Since the Laggard did not invest according to Nash, the Leader would respond by reduce his investment level (because investments are strategic complements). The most likely reason is that the Leaders overcompensated their reduction in investment. Doing this would lead them to be classified as "loss lovers", even if the reason for underinvestment comes from not knowing the response for the Laggards.

Table 16: Results: Loss aversion in NO Sharing

Competition	Role	Feeling of loss
Moderate	Symmetric	16
Soft	Leader	-125
	Laggard	-12
Moderate	Leader	-128
	Laggard	-1
Tough	Leader	-23
	Laggard	177

There is more loss aversion observed in Sharing than no Sharing. This observation can be explained by the fact that the probability for failure in Sharing is lower than for no Sharing. Hence loss averse subjects would share knowledge to reduce their chances for failure rather than do-it-alone (no Sharing). Summing up, this loss aversion model has more explanatory power in the Sharing cases than the NO Sharing cases.

5.4 Cooperation

Thy way this experiment was constructed cooperating would be extremely difficult. Two factors worked against the subjects: First, the subjects choose their level of investment at the same time, giving subjects the incentive to deviate from a cooperative equlibrium. Second, the subjects would be paired up with a random opponent every period. There was no indication of who their opponent was. Not only did this work against the subjects, but this design is specifically made to make sure that subjects do not cooperate. Cooperation on the other hand, seems nearly to be a part of human nature (Dawes & Thaler, 1988).

Table 17: Results: Cooperation in Sharing

Competition	Role	R&D			Profit			
		Nash	Coop	Mean (sd)	Nash	Coop	Mean (sd)	n
Moderate	Symmetric	226	260	341 (124)	313	317	308 (350)	188
Soft	Leader	300	360	337 (187)*	515	524	483 (327)	70
	Laggard	300	360	416 (152)	315	324	287 (297)	70
Moderate	Leader	226	260	255 (198)*	420	424	343 (396)	61
	Laggard	226	260	365 (201)	220	224	161 (313)	61
Tough	Leader	162	180	256 (217)	341	342	233 (469)	45
	Laggard	162	180	276 (205)	141	142	-58 (78)	45

* 5% significance level

Table 18: Results: Cooperation in NO Sharing

Competition	Role	R&D			Profit			
		Nash	Coop	Mean (sd)	Nash	Coop	Mean (sd)	n
Moderate	Symmetric	547	900/0	557 (175)	204	525 / 30	152 (379)	132
Soft	Leader	733	800	575 (227)	416	680	276 (369)	90
	Laggard	533	0	600 (274)	142	0	149 (337)	90
Moderate	Leader	780	800	530 (216)	461	680	256 (409)	99
	Laggard	314	0	488 (248)	49	0	107 (349)	99
Tough	Leader	800	800	542 (169)	680	680	213 (478)	115
	Laggard	0	0	435 (275)	0	0	-2 (329)	115

The Table above shows there are only two cases where the subjects investment levels were not significantly (at even the 10% level) different from the cooperation level. The Leader in Soft and Moderate cases with Sharing had significant investment level to maximize joint profit. For the no sharing cases there were no level even close to cooperation.

This is not exactly surprising because of the enormous asymmetry cooperation predicted. Laggards were not willing to not invest so that their counterpart could capture the market. With so few cooperation observed one can conclude that was a whole there was no cooperation in this experiment.

In sharing there is not much extra profit to gain by setting a cooperative R&D level. This is another factor that would remove incentives to cooperate.

6. Discussion / Conclusion

The analysis and comparisons completed, we can now address the predictions of the experiment and answer if any anomalies were observed. In this thesis, these predictions have been discussed in relation to actual behavior through this experiment. How did the different market conditions affect predictions? What differences did asymmetric initial knowledge lead to?

The predictions and results for Treatment 1 (symmetric treatment) gave by far the most consistent results. The subjects showed tendencies to risk aversion in the whole treatment. Loss aversion was also prominent, with positive values of loss aversion for both Sharing and NO Sharing. For the No Sharing case the subjects invested fairly close to their Nash equilibrium. In this Treatment subjects over average decided to share knowledge, which in return gave them higher profits.

Treatment 2 (asymmetric Soft) also gave results that were fairly consistent with the prediction models. Risk aversion were observed in three of the four different outcomes (Leader/Laggard and Sharing/NO Sharing). Loss aversion only held for the sharing case, subjects were a lot closer to Nash in the sharing cases. In this treatment we should have expected more sharing of knowledge, as the subjects should in theory and in practice be better off by Sharing.

Treatment 3 (asymmetric Moderate) had dominant strategy (in theory and practice) to share knowledge, but the subjects opted not to share knowledge. This treatment showed risk aversion and loss aversion for the sharing case, but risk loving and loss loving strategies for the NO sharing cases. This is due to overinvestment from the Laggard and underinvestment from the Leader. This can be interpreted as the breakdown of the model. Subjects seemed to prefer NO sharing (which was the Nash equilibrium).

Treatment 4 (asymmetric Tough) was the treatment that was hardest to predict. Especially in the NO sharing case, with massive overinvestment from the Laggard and massive underinvestment from the Leader none of the analysis gave any reasonable explanation for this case. Again for the sharing case the subjects “behaved” well, with risk aversion and loss aversion being observed. This does raise the question why do Laggards overinvest so much?

It could be that Laggards with a sense of fairness wishes to punish Leaders who do not wish to share knowledge. This is unfortunately not investigated in this thesis. This could be investigated in another experiment. An experiment could force subjects to share knowledge (or force them to not share knowledge) for the first half. Thereafter give them the option to share knowledge in the second half. There could be different investment levels when the subjects themselves choose sharing agreements.

Hypothesis 1: Subjects that exchange knowledge will implicitly cooperate on the R&D level. Cooperative investment level was only observed in two cases in this experiment, for the Leader in sharing Soft and Moderate markets. Because of so few observations of cooperative investment levels we reject the hypothesis that the subjects were cooperating.

Hypothesis 2: Subjects behave risk averse. Risk aversion for expected utility performed better than mean variance risk aversion. The risk aversion hypothesis (for expected utility) held for the sharing cases, but only for two of the seven NO Sharing cases. For the sharing cases the subjects were willing to reduce expected profit, thereby increasing the chances of receiving a smaller payoff.

Hypothesis 3: Subjects behave loss averse. Loss aversion can only be said to hold for the sharing cases, but again it did not hold for the NO Sharing cases.

Hypothesis 4: Subjects that on average more frequently try to form cooperation with their counterpart will choose a more cooperative level of R&D. This hypothesis held for nearly all sharing cases. For all but the Tough cases, the Team players chose a less aggressive investment level than the Individualists (two of these cases just barely missed being significant at the 5% level). The Tough case was not significant at all. For the NO Sharing cases all but one did not show any significant difference between Team players and Individualists. The Leader in the Moderate case showed a significant difference in investment. It is not clear why.

Hypothesis 1 was rejected. Hypothesis 2, 3 and 4 all held for the sharing cases (with a few exceptions for hypothesis 4). Why did not the hypothesis hold in all cases? There can be several reasons why these hypotheses failed. The classification of these anomalies is based on experiments that were specifically designed to test for anomalies, testing for only one anomaly at the time. There could be specific conditions that need to be met for some anomalies to occur that we have not taken in to account. There could be errors with the models. There could be logical error along the way. The supporting assumptions might be wrong.

On the empirical side, with the experiment only lasting for 16 periods, it might be that the subjects did not have enough experience and time to figure out their best strategy. Subjects only had 30 seconds to reach their decisions. There are a few other factors that should be mentioned that could affect the outcome of this experiment. There was limited liability for the subjects participating in this experiment. Hence the subjects could never loose money by participating. If the subjects were unsure what to do the "Trembling hand" effects could come in to play (Selten, 1983). Other effects could be bounded rationality (Simon, 1991). K-level thinking could also have been present in this experiment (Crawford & Iriberri, 2007).

This is not as conclusive an answer that I would have liked to present. However, since the sharing decision and the investment decision were different than predicted by the Nash equilibrium there seems to be some anomalies present. Though finding and classifying them is a different matter.

With the argument that there might be special conditions that cause certain anomalies, there could be indications from this experiment that either loss aversion or risk aversion are more prominent when subjects cooperate (in this experiment share knowledge) or there is some anomaly that is not accounted for when the subjects do not cooperate, or maybe both.

Further research of interest would be to investigate under what conditions anomalies are observed. If economists can predict under what conditions different anomalies will occur, this could be one step in the process to develop new models.

Since this experiment simulates the interaction of firms in an invention race, there are other alternatives that could be interesting to look in to. With firms that do investment some go bankrupt, and bad firms are removed from the market. What could be interesting is to invite back the subjects that performed over average (representing firms that did not fail), and have them play the experiment again. This could investigate if there is more stability in markets where bad firms are allowed to fail.

What can experimental economics do for theory? And, what can theory do for experimental economics? Many economists in many papers have tried to answer these questions, though nothing conclusive. Daniel Friedman and Alessandra Cassar (2004) argues that experiments should be used to discriminate between alternative theories and to test the robustness of single relevant theories. They comment that experiments could be used for several nonscientific purposes. Vernon L. Smith (1989) argues that the results gathered by experiments should make us skeptical of both the theory and the evidence, to make us seek improvements for both theory and the methods of testing. Larry Samuelson (Samuelson, 2005) also argues that economic theory and economic experiments can be combined to benefit both economic theory and experimental economics. More importantly he argues that we can use experiments not just to test theory, but also to investigate other issues of economic importance.

Anomalies violate standard theory. In many cases there are no obvious way of incorporating them into theory. Kahneman, Knetsch and Thaler (1991) argues that either there is too little known about specific anomalies or that incorporating them in to general models would greatly increase the complexity of theory.

This thesis provides a vivid illustration of the many problems that may occur in the encounter between theory and experiments.

7. References

Bodie, Kane, & Marcus. (2009). *Investments* (8th ed.): Mc Graw Hill.

Clark, D., Østbye, S., & Roelofs, M. (2010). Should birds of a feather flock together? Theory and experiments on knowledge sharing in reaserch and development; Mimeo, Universety of Tromsø.

Crawford, V. P., & Iriberri, N. (2007). Level-K Auctions: Can a Nonequilibrium Model of Strategic Thinking Explain the Winner's Curse and Overbidding in Private-Value Auctions? *Econometrica*, *75*(6), 1721-1770.

Dawes, R. M., & Thaler, R. H. (1988). Anomalies: Cooperation. *The Journal of Economic Perspectives*, *2*(3), 187-197.

Fischbacher, U. (2007). z-Tree: Zurich toolbox for ready-made economic experiments. *Experimental Economics, 10*(2), 171-178.

Friedman, D., & Cassar, A. (2004). Economistst go to the laboratory *Economics Lab*: Routledge.

Güth, W., Schmittberger, R., & Schwarze, B. (1982). An experimental analysis of ultimatum bargaining. *Journal of Economic Behavior & Organization, 3*(4), 367-388.

Hertwig, R., & Ortmann, A. (2001). Experimental prectices in economics: A methodological challenge of psychologists? *Behavioral and Brain Sciences*, 383-403.

Kahneman, D., Knetsch, J. L., & Thaler, R. (1986). Fairness as a Constraint on Profit Seeking: Entitlements in the Market. *The American Economic Review*, *76*(4), 728-741.

Kahneman, D., Knetsch, J. L., & Thaler, R. H. (1991). Anomalies: The Endowment Effect, Loss Aversion, and Status Quo Bias. *The Journal of Economic Perspectives*, *5*(1), 193-206.

Knetsch, J. L., & Sinden, J. A. (1984). Willingness to Pay and Compensation Demanded: Experimental Evidence of an Unexpected Disparity in Measures of Value. *The Quarterly Journal of Economics*, *99*(3), 507-521.

Lakshminarayanan, V. R., Chen, M. K., & Santos, L. R. (2011). The evolution of decision-making under risk: Framing effects in monkey risk preferences. *Journal of Experimental Social Psychology, 47*(3), 689-693.

Lowenstein, & Kahneman. (1991). Explaining the endowment effect.

Morgan, J. P., Chaganty, N. R., Dahiya, R. C., & Doviak, M. J. (1991). Let's Make a Deal: The Player's Dilemma. *The American Statistician, 45*(4), 284-287.

Page, S. E. (1998). Let's make a deal. *Economics Letters, 61*(2), 175-180.

Rabin, M., & Thaler, R. H. (2001). Anomalies: Risk Aversion. *The Journal of Economic Perspectives, 15*(1), 219-232.

Samuelson, L. (2005). Economic Theory and Experimental Economics. *Journal of Economic Literature, 43*(1), 65-107.

Selten, R. (1983). Evolutionary stability in extensive two-person games. *Mathematical Social Sciences*, *5*(3), 269-363.

Simon, H. A. (1991). Bounded Rationality and Organizational Learning. *Organization Science, 2*(1), 125-134.

Thaler, R. H. (1988). Anomalies: The Ultimatum Game. *The Journal of Economic Perspectives, 2*(4), 195-206.

Thaler, R. H., Tversky, A., Kahneman, D., & Schwartz, A. (1997). The Effect of Myopia and Loss Aversion on Risk Taking: An Experimental Test. *The Quarterly Journal of Economics, 112*(2), 647-661.

Tversky, A., & Kahneman, D. (1981). The framing of decisions and the psychology of choice. *Science, 211*(4481), 453-458.

Tversky, A., & Kahneman, D. (1991). Loss Aversion in Riskless Choice: A Reference-Dependent Model. *The Quarterly Journal of Economics*, *106*(4), 1039-1061.

Tversky, A., & Kahneman, D. (1992). Advances in prospect theory: Cumulative representation of uncertainty. *Journal of Risk and Uncertainty, 5*(4), 297-323.

Vernon, L. S. (1989). Theory, Experiment and Economics. *The Journal of Economic Perspectives, 3*(1), 151-169.

Vernon, L. S. (1994). Economics in the Laboratory. *The Journal of Economic Perspectives, 8*(1), 113-131.

Østbye, S., & Roelofs, M. (2011). The competition-inovation debate: Is R&D cooperation the answer?; Mimeo, Universety of Tromsø.

8. End note

1) Figured created by myself.
2) Taken from (Lakshminarayanan, et al., 2011), presenting Tversky and Kahnemans' problem.
3) Figure taken from (Lakshminarayanan, et al., 2011).
4) This graph is taken from (http://randomly-walking.blogspot.com/2010_08_01_archive.html)
5) Analysis of strategic interaction with bounded rationality could be pursued using the concept of k-level thinking (Crawford & Iriberri, 2007)

9. Appendix

Cumulative probability function expanded.

$$P_i(x_i, x_j) = \begin{cases} x_i + \alpha x_j + \mu_i \; if \; [x_i + \alpha x_j + \mu_i \leq 1] \\ 1 \; if \; [x_i + \alpha x_j + \mu_i \; > 1] \end{cases}$$

Expected profit

$$E[\pi_i] = (x_i + \mu_i + \alpha x_j)[\pi_m + (x_j + \mu_j + \alpha x_i)(\pi_d - \pi_m)] - \frac{x_i^2}{2}$$

Parameter restriction

$$x_{i,j} \epsilon [0,1]$$

$$E\pi_i = F_i((1 - F_j)\pi_m + F_j\pi_d) - \frac{x_i^2}{2}$$

$$E\pi_i = F_i[\pi_m + F_j(\pi_d - \pi_m)] - \frac{x_i^2}{2}$$

$$E\pi_i = (x_i + \mu_i + \alpha x_j)[\pi_m + (x_j + \mu_j + \alpha x_i)(\pi_d - \pi_m)] - \frac{x_i^2}{2}$$

$$E\pi_i = (x_i + \mu_i + \alpha x_j)[\pi_m + (x_j + \mu_j + \alpha x_i)(\pi_d - \pi_m)] - \frac{x_i^2}{2}$$

Derivate and set equal to zero

$$\frac{\partial E\pi_i}{\partial x_i} = (x_i + \mu_i + \alpha x_j)\alpha[\pi_d - \pi_m] + \pi_m + (x_j + \mu_j + \alpha x_i)(\pi_d - \pi_m) - x_i = 0$$

$$x_i = \frac{\pi_m + (x_j + \mu_j)[\pi_d - \pi_m] + (\mu_i + \alpha x_j)\alpha[\pi_d - \pi_m]}{c - 2\alpha(\pi_d - \pi_m)}$$

$$x_i = \frac{\pi_m + [(1 + \alpha^2)x_j + \mu_j + \alpha\mu_i][\pi_d - \pi_m]}{1 - 2\alpha(\pi_d - \pi_m)}$$

$$x_i = \frac{\pi_m - x_j(1 + \alpha^2)(\pi_m - \pi_d) - (\mu_j + \alpha\mu_i)(\pi_m - \pi_d)}{1 + 2\alpha(\pi_m - \pi_d)}$$

$$\pi_m - \pi_d > 0$$

$$1 + 2\alpha(\pi_m - \pi_d) > 0$$

$$\frac{\partial x_i}{\partial x_j} = \frac{(1 + \alpha^2)(\pi_d - \pi_m)}{1 - 2\alpha(\pi_d - \pi_m)} < 0$$

$$x_i = \frac{\pi_m - x_j(1 + \alpha^2)(\pi_m - \pi_d) - (\mu_j + \alpha\mu_i)(\pi_m - \pi_d)}{1 + 2\alpha(\pi_m - \pi_d)}$$

$$x_i = \frac{\pi_m - (\mu_j + \alpha\mu_i)(\pi_m - \pi_d) - (1 + \alpha^2)(\pi_m - \pi_d)\left\{\frac{\pi_m - (\mu_i + \alpha\mu_j)(\pi_m - \pi_d) - (1 + \alpha^2)(\pi_m - \pi_d)x_i}{1 + 2\alpha(\pi_m - \pi_d)}\right\}}{1 + 2\alpha(\pi_m - \pi_d)}$$

$$x_i = \frac{(\pi_m - (\mu_j + \alpha\mu_i)(\pi_m - \pi_s)\big(c + 2\alpha(\pi_m - \pi_s)\big) - (1 + \alpha^2)(\pi_m - \pi_s)\{\pi_m - (\mu_i + \alpha\mu_j)(\pi_m - \pi_s) - (1 + \alpha^2)(\pi_m - \pi_s)x_i\}}{\big(1 + 2\alpha(\pi_m - \pi_s)\big)^2}$$

$$x_i = \frac{(\pi_m - (\mu_j + \alpha\mu_i)(\pi_m - \pi_s)\big(c + 2\alpha(\pi_m - \pi_s)\big) - (1 + \alpha^2)(\pi_m - \pi_s)\{\pi_m - (\mu_i + \alpha\mu_j)(\pi_m - \pi_s)\} + [(1 + \alpha^2)(\pi_m - \pi_s)]^2 x_i}{\big(1 + 2\alpha(\pi_m - \pi_s)\big)^2}$$

$$x_i \left\langle 1 - \frac{[(1 + \alpha^2)(\pi_m - \pi_s)]^2}{\big(1 + 2\alpha(\pi_m - \pi_s)\big)^2} \right\rangle = \frac{(\pi_m - (\mu_j + \alpha\mu_i)(\pi_m - \pi_s)\big(c + 2\alpha(\pi_m - \pi_s)\big) - (1 + \alpha^2)(\pi_m - \pi_s)\{\pi_m - (\mu_i + \alpha\mu_j)(\pi_m - \pi_s)\}}{\big(1 + 2\alpha(\pi_m - \pi_s)\big)^2}$$

$$x_i = \frac{(\pi_m - (\mu_j + \alpha\mu_i)(\pi_m - \pi_s)\big(c + 2\alpha(\pi_m - \pi_s)\big) - (1 + \alpha^2)(\pi_m - \pi_s)\{\pi_m - (\mu_i + \alpha\mu_j)(\pi_m - \pi_s)\}}{\big(1 + 2\alpha(\pi_m - \pi_s)\big)^2 - [(1 + \alpha^2)(\pi_m - \pi_s)]^2}$$

Screen shoots from the experiments

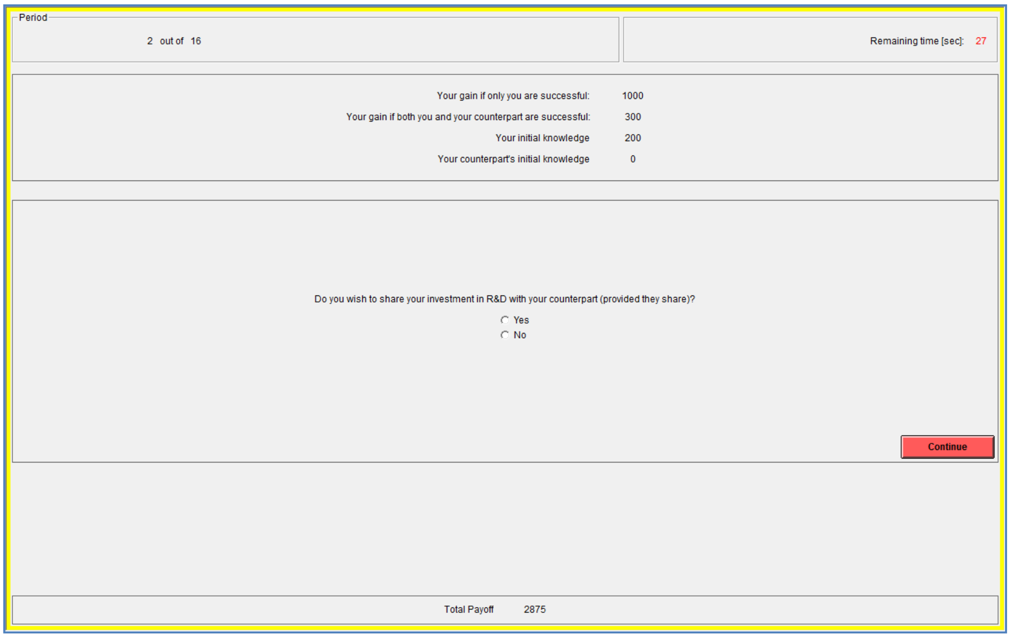

Figure 13: From the experiment: Cooperation Screen

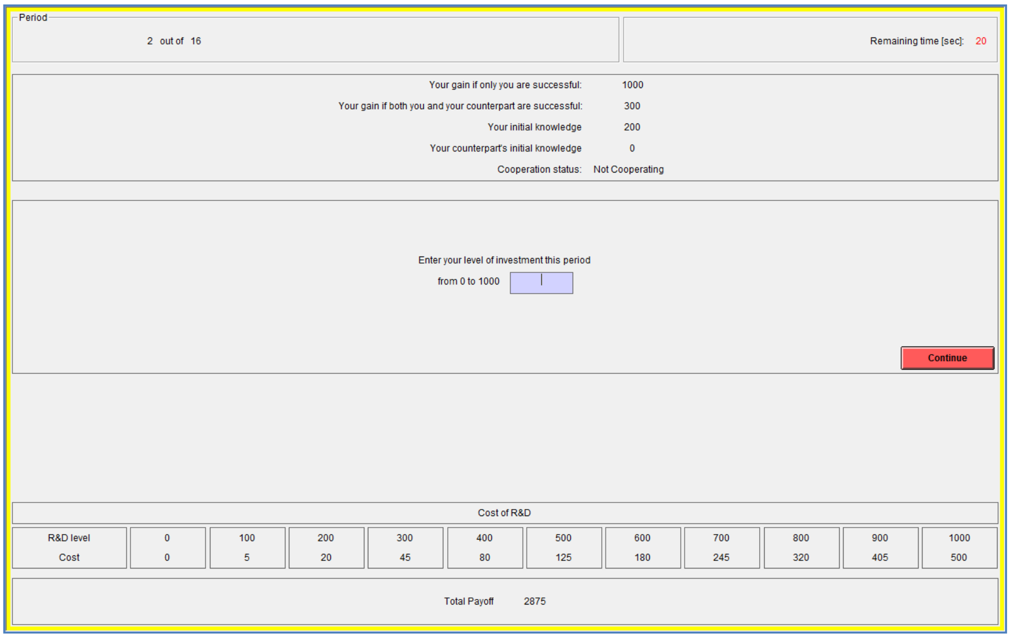

Figure 14: From the experiment: Investment Screen

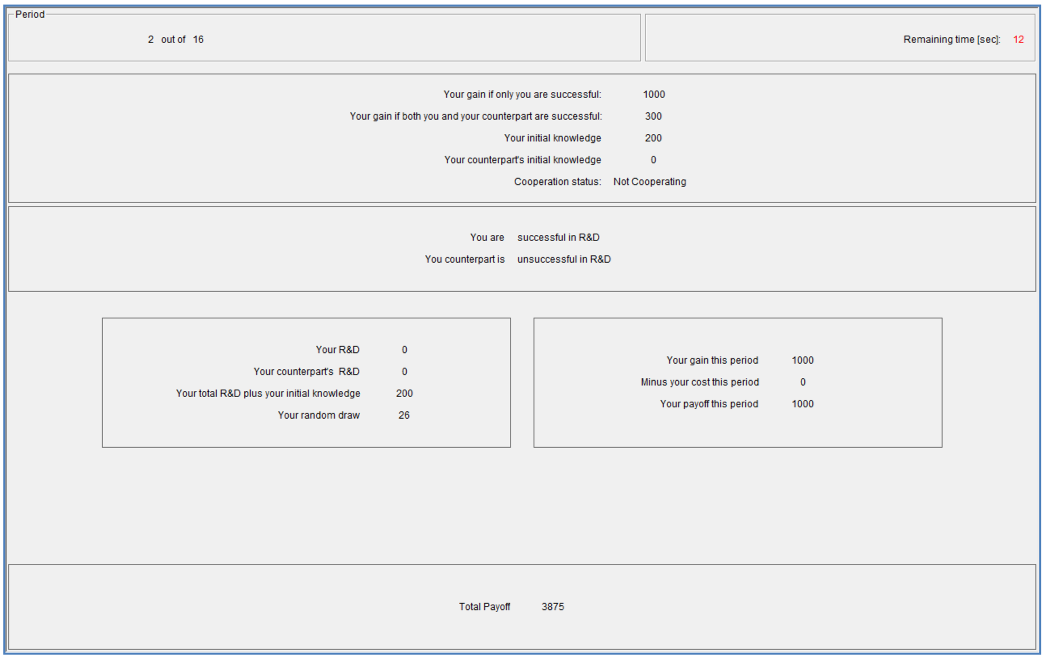

Figure 15: From the experiment: Result Screen

Mean variance graphs

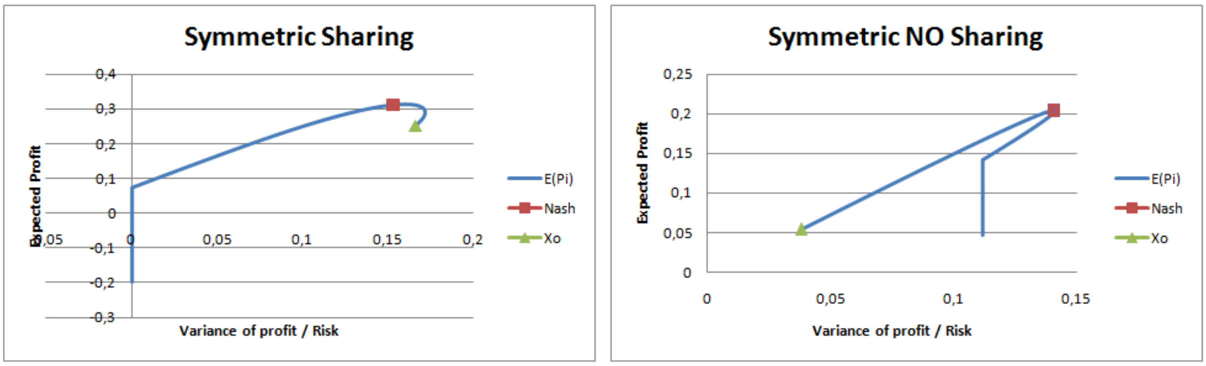

Figure 16: Mean risk aversion Symmetric

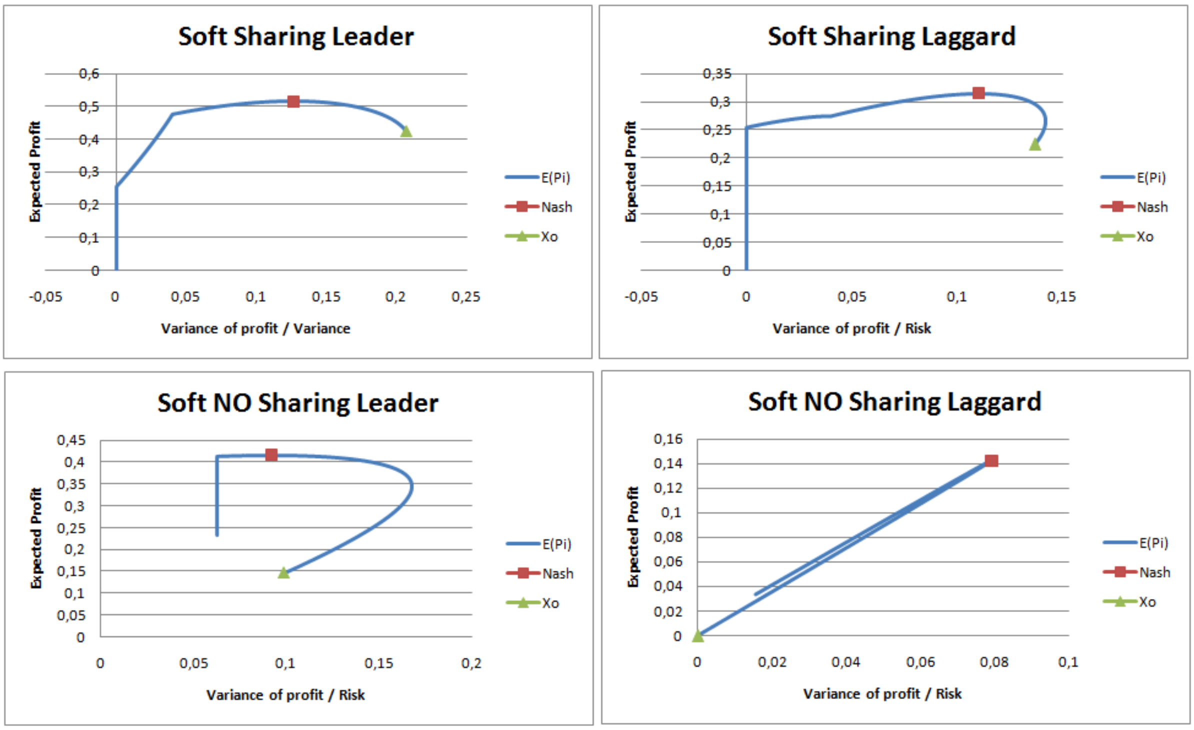

Figure 17: Mean risk aversion Soft

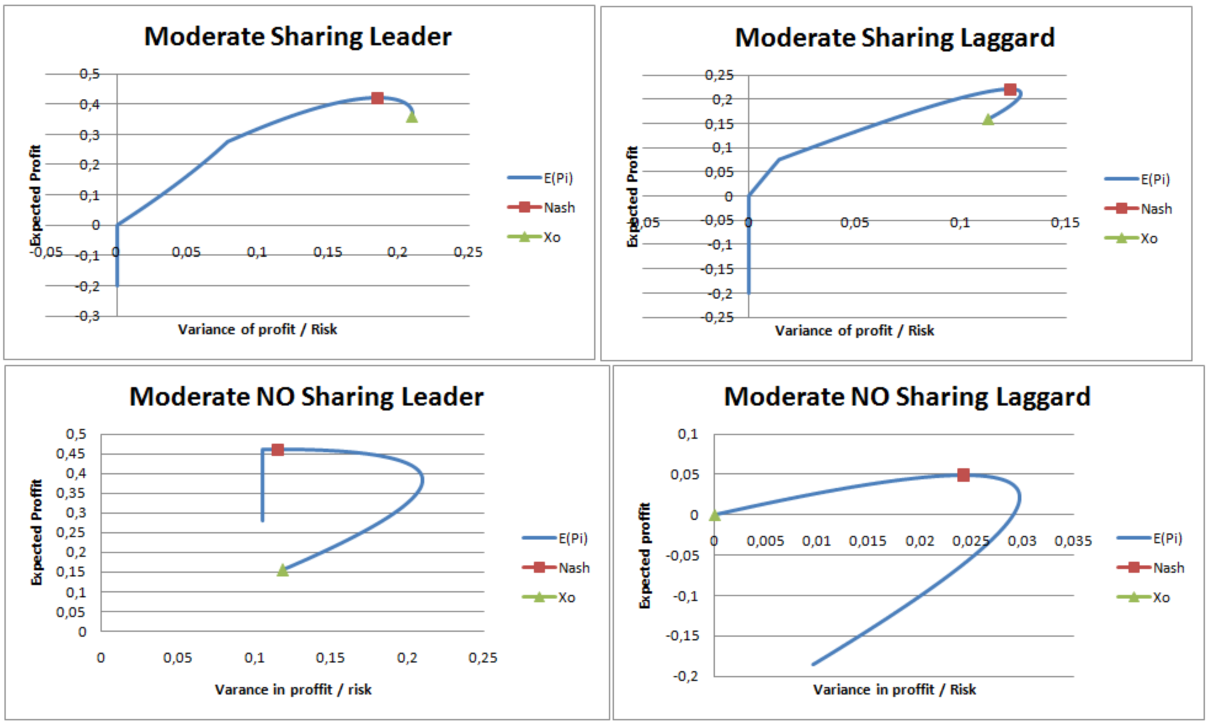

Figure 18: Mean risk aversion Moderate

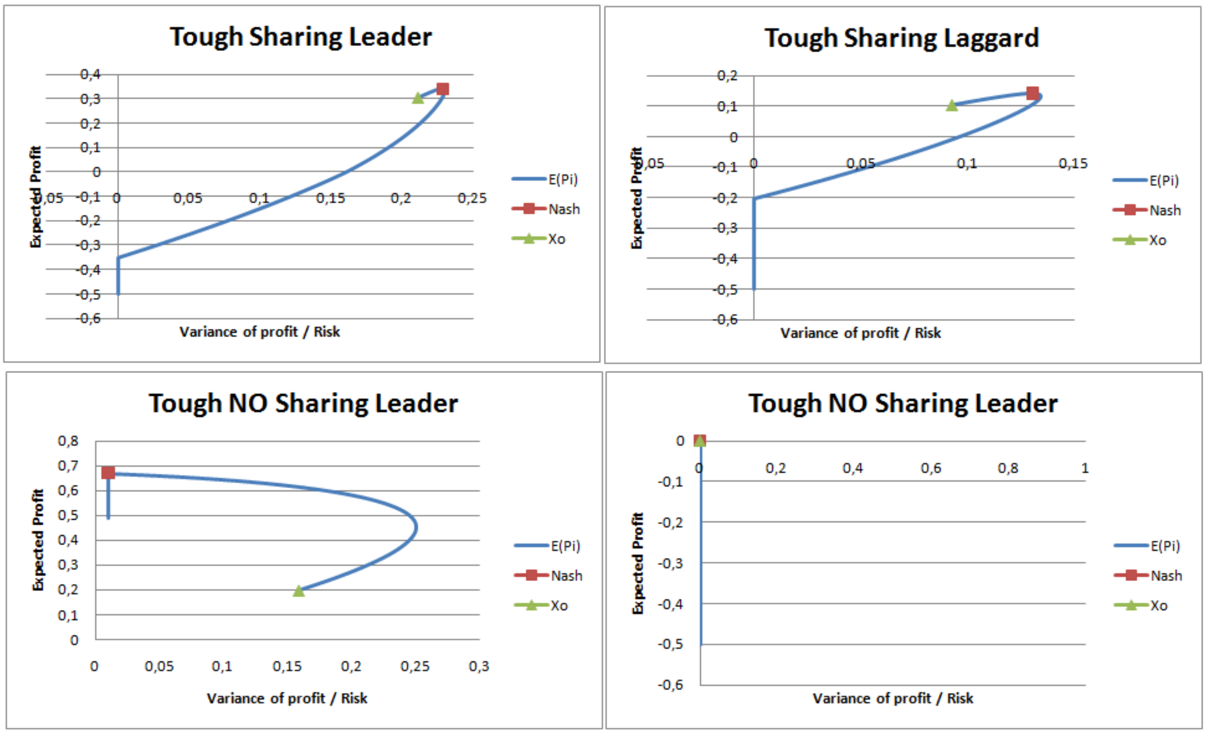

Figure 19: Mean risk aversion Tough