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An Analysis of Ecological and Social Rationality: When are Lexicographic Heuristics Preferred?

Dong-Gook Kim

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AN ANALYSIS OF ECOLOGICAL AND SOCIAL RATIONALITY: WHEN ARE LEXICOGRAPHIC HEURISTICS PREFERRED?

BY

DONG-GOOK KIM

A Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree
of
Doctor of Philosophy
in the Robinson College of Business
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ACCEPTANCE

This dissertation was prepared under the direction of the candidate's Dissertation Committee. It has been approved and accepted by all members of that committee, and it has been accepted in partial fulfillment of the requirements for the degree of Doctor in Philosophy in Business Administration in the Robinson College of Business of Georgia State University.

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ABSTRACT

AN ANALYSIS OF ECOLOGICAL AND SOCIAL RATIONALITY: WHEN ARE LEXICOGRAPHIC HEURISTICS PREFERRED?

By

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In their book, Gigerenzer and Selten (2001) described human being as an organism that adaptively reacts to its environment by selecting ecologically rational heuristics that are contingent on task demands; that is, adaptivity assumption. Empirical evidence of the adaptivity assumption is, however, mixed. In this paper, I review prior experiments related to testing the adaptivity assumption and criticize some of the past findings. From this criticism, the research questions are formed. The research objective of this paper is to test whether or not people choose their decision strategy as a reaction to environmental conditions.

In this dissertation, the use of the take-the-best (TTB) heuristic is investigated for different treatments, which are information structure, information cost, and social rationality. Participants go through 180 trials of a pair comparison task. Using the proportion of TTB trials as a dependent variable, three hypotheses regarding the effects of three treatments are tested. The results of the experiments indicate that only the social rationality is a significant factor in promoting the TTB heuristic. Besides the test of the hypothesis, an exploratory analysis of participants' data is presented.

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Chapter 1

Introduction

The fast and frugal heuristics, proposed by Gigerenzer and colleagues (e.g., Gigerenzer and Goldstein, 1996), are a set of heuristics that take an advantage of environmental structures to make a *good* decision quickly while using little resource. Despite frugal use of resources, the performances of the fast and frugal heuristics, when measured through mathematics and/or simulation, are comparable to or even better than those of the classical models of human decision making, which use more resources than the fast and frugal heuristics (Martignon and Hoffrage, 1999).

Such a trait of good performance with less resource helps the fast and frugal heuristics to gain a great popularity in the recent study of decision making under uncertainty. Researchers have tested empirically whether people employ the fast and frugal heuristics. Among various fast and frugal heuristics, the take-the-best (TTB) heuristic has been tested the most often. The TTB heuristic is a heuristic used for an inference task when two alternatives are concerned. For example, what stock between two alternatives is more profitable? The TTB heuristic provides simple rules for how to search information, when to stop the information search, and how to make a decision based on the searched information.

A few studies (e.g., Bröder, 2000) tested empirically whether or not people use the TTB heuristic and found that the latter heuristic was used but not consistently. A handful of studies (e.g., Bröder, 2000, 2003; Newell et al., 2003; Newell and Shanks, 2003) have tested conditions under which the TTB heuristic is more likely to be used, and findings of such studies are not concrete yet. Recently, B. Newell et al. (2003) designed an experiment, based on the past experiments (e.g., Bröder, 2000), that promoted strongly the use of the TTB heuristic. They explained the objective of their study as follows:

> . . . we ask whether an experimental environment can be constructed in which we might observe a higher proportion of participants adhering to the strategy, and thus provide further insight into the conditions under which particular heuristics [e.g., the TTB heuristic] are used. (p. 84)

The results of their experiments indicated that they had not found such conditions yet. The authors found that almost 70% of participants did not employ the TTB heuristic in the experiments. They suggest that "either the heuristic is only adopted by a minority of the population and thus that its psychological reality is doubtful, or that we [B. Newell et al.] are still just 'looking in the wrong place' for the conditions that promote its use."

However, I suggest that their experiments may have not been designed to promote the use of the TTB heuristic better than they could have been. This is because their results could have been confounded by some of their experimental settings. From the finding of this possibility, I thought I could improve their experimental designs, and that is how this dissertation started. The research objective of this paper is to test whether people choose their decision strategy as a reaction to environmental conditions, that is, the *adaptivity assumption*. In addition, the results of the study will check the adequacy of past experimental designs in testing the use of the TTB heuristic.

In this dissertation, I examine three factors or conditions that may have affected the results of B. Newell et al.'s (2003) experiments, which are information structure, information cost, and social rationality. The theory of ecological rationality and a survey of recent empirical studies of the TTB heuristic suggests that these proposed factors may have affected the results of B. Newell et al.'s experiments. Based on these three factors, three research hypotheses are formulated. I propose that the result of this dissertation can shed more insight on whether or not the past results were confounded by the experimental settings and can provide a clearer picture regarding the conditions that promote the use of the TTB heuristic well.

To test the research hypotheses, I first replicate the experiment of B. Newell et al., which serves as a base case for this dissertation. Each of the three factors serves as a treatment to the experiment. The value of a dependent variable in the base case and that in the treatment case are then compared to test the hypothesized effect of the treatment. The test results show that people are *conditionally* adaptive to an environment. In addition, the past experimental designs are found not to be the best one for testing the use of the TTB heuristic, and possible improvements on experimental designs are suggested. Lastly, findings from exploratory analysis of the data are also reported.

An assumptions about rationality of human being is an important issue in practically all cognitive sciences explaining human behavior and many social phenomena (Shafir and LeBoeuf, 2002). The adaptivity assumption tested in this study is based on ecological rationality. While the ecological rationality is fairly new, strict rationality has been studied and used for a long time.

The theories of strict or unbounded rationality provide a model by which an agent can achieve *the best* possible decision for a certain criterion (e.g., expected utility). Examples of such theories include subjective utility theory (von Neumann and Morgenstern, 1944) and decision analysis (Raiffa and Schlaifer, 1961). Models of strict rationality suggest how a decision should be made and what kind of outcome should be arrived for given conditions. The theories of strict rationality provide simplicity and convenience of mathematical calculation for solving the models of how an agent will behave or should behave (Gigerenzer and Todd, 1999). These theories are believed to be a reasonable approximation for explaining and predicting human behavior (Shafir and LeBoeuf, 2002). However, empirical findings suggest that there is a discrepancy between what the models suggest and actual human behaviors (Gilovich et al., 2002).

Herbert Simon suggested that the model of the human mind should portray the limited capability of human mind realistically, and consequently, he proposed the theory of bounded rationality (Simon, 1956; Newell, 1972), which provides a model by which an agent can achieve a *good* decision with reasonable amount of calculation and use of resources. Such consideration of the limitations imposed on a decision maker, such as limited capability of human mind and limited availability of resources, is the main feature that distinguishes bounded rationality from strict rationality. The theory of ecological rationality was proposed based on the theory of bounded rationality, and it emphasizes the role of an environment in decision making (Gigerenzer and Goldstein, 1996).

Ecological rationality means that both a decision itself and the way the decision is made are adaptive to an environment. In their book, Gigerenzer and Selten (2001) emphasize the importance of the environment by describing the human being as an organism that adaptively reacts to its environment by selecting ecologically rational heuristics that are contingent on task demands. The role of the environment in affecting observed human behavior has been recognized before the school of ecological rationality, however. Ecological psychology (e.g., Barker, 1968; Gibson, 1979) is one of the schools recognized such an importance. The title of Mace's (1977) article neatly captures Gibson's view toward the environment in explaining behavior of organisms: "Ask not what's inside your head, but what your head's inside of." Another scholar who recognized the importance of an environment was Herbert Simon. In his book, Simon (1981) used an ant on a beach as an example of how environments affected the behavior of an organism:

> Viewed as a geometric figure, the ant's path is irregular, complex, hard to describe. But its complexity is really a complexity in the surface of the beach, not a complexity in the ant.

That is, the ant was adaptive to the environment by applying a simple strategy: keep walking and go around the obstacles, such as water, pebbles and rocks. He asserted that this idea also applies to many things including human behavior. While the environment is important aspect of rational behaviors, the computational capability (i.e., possible strategies employed and run) of an agent is also as important (Simon, 1990). Due to their limited capability of computations, organisms do not optimize in general; rather they satisfice (Simon, 1956). Ecological rationality camp asserts that ecological rationality is a pure form of bounded rationality in that the former requires the use of even less resources than the latter.

This paper is organized as follows. Chapter 2 provides a review of the prior literature. I first survey different theories of rationality: unbounded, bounded, and ecological rationality. This is followed by the discussion of the TTB heuristic. Then this chapter reviews prior experiments related to the fast and frugal heuristics. Chapter 3 develops research questions and hypotheses based on the findings of the prior experiments. Chapter 4 discusses the methodology, experimental settings and procedures used in this dissertation. Chapter 5 presents the results of the data analysis. Chapter 6 summarizes this dissertation by discussing the findings, the major contributions, the limitations, and future directions of the study.

Chapter 2

Literature Review

A lot of effort has been made to model the cognitive process of a rational man. Such models are used to describe how decisions are made (i.e., a descriptive model), to predict how people will behave (i.e., a prescriptive model), and to state how people should behave (i.e., a normative model). In what follows, I survey some of the important theories of rational decision making and their role in the study of human rationality.

Since Smith's (1776) metaphor "the invisible hand", one of the main tasks of economic theories is to study the process of an interaction of many individual agents in a decentralized economy (Vriend, 1996). The invisible hand means that agent's actions based on his own selfishness result in unplanned or unintended consequences, which are beneficial to a society (Nozick, 1974; Ullmann-Margalit, 1978). The most famous quote pertaining to this point is:

> It is not from the benevolence of the butcher, the brewer, or the baker, that we expect our dinner, but from their regard to their own interest. We address ourselves not to their humanity, but to their self-love, and never talk to them of our necessities, but of their advantage. (Smith, 1776, p. 26/27)

Since then, the self-interest becomes a cardinal characteristic of economic man or homo economicus. A behavior of homo economicus can be described by three characteristics: self-interest, perceived opportunities, and preference; Vriend (1996) write:

> Homo oeconomicus is an agent with given preferences, pursuing his self-interest, seeking to do the best he can given his opportunities. (p. 265)

Since the perceived opportunity set is always non-empty, there is always a preferred choice. As “it is not for economists to make any claims about their [i.e., economic men’s] preferences,” rationality of homo economicus was not questioned, at least not in classical economics (Vriend, 1996, p.273). However, in neo-classical economics, new theories regarding rationality emerged, which tried to explain many economic and social phenomena. These new theories recognized that “A person is entitled to a wide range of opinions, beliefs, and preferences; what is important is for these to cohere in a normatively defensible fashion” (Shafir and LeBoeuf, 2002, p. 492).

Expected utility theory is one of such new theories of rationality, and its earliest form can be found in 1738 in Daniel Bernoulli’s article (1738). He was working on the problem called St. Petersburg paradox. This is a game with infinite expected monetary value. Therefore, one should pay any finite amount to play this game. However, people would not pay much to play such a game; that is the paradox. Bernoulli’s solution was to use utility instead of money to value the outcomes of the game. He suggested a logarithmic utility function, which has decreasing marginal return on wealth. That is, for example, an increase of the prize by $1,000 would be far less significant if a gambler’s wealth stood at $1,000,000 than if it only stood at $1,000. Using such a utility function, Bernoulli found that the expected utility is finite, even though expected monetary value is infinite. However, he did not explain why following expected utility was rational (Savage, 1972).

Later, in their book, von Neumann and Morgenstern (1944) proved that expected utility theory is a rational criterion of decision making under risk. From the theory, several axioms of rationality are derived. The axioms imply that there exist utility indexes that are perfectly coincide with the person’s actual preferences (Schoemaker, 1982), and following the axioms ensure that a decision maker behaves in a coherent manner.

In the expected utility theory, utility of an outcome is defined as equal to the probability of winning a lottery such that the individual is indifferent between receiving the outcome for sure and accepting the lottery (Waston and Buede, 1987). Therefore, the utility is defined in terms of risk preferences of a decision maker. If a decision maker prefers a sure outcome, then he is said to be risk averse; if he prefers a lottery, he is said to be risk seeking.

The expected utility theory asserts that people choose an action or alternative with the highest expected utility. The expected utility of an alternative can be obtained as follows. Given an alternative, first, define a utility of each outcome and get the probability of obtaining that outcome. Then, these two are multiplied, and this product is added across the all possible outcomes of the alternative. Note that the probability used in the expected utility theory is objective one.

Many empirical test showed that human behaviors are not consistent with what the model suggests, however (Schoemaker, 1982). Because of these findings, the descriptive role of the expected utility theory in human decision making was challenged, and changes were needed. Out of such a necessity, subjective expected utility (SEU) theory and prospect theory was developed. The former uses a subjective probability instead of an objective probability of obtaining an outcome, and the latter used different form of both a probability (indeed it is not probability) and utility.

With dissatisfaction with the expected utility theory, objective probability was replaced with subjective probability (Edwards, 1961). The subjective probability is closely related to Bayesian probability and Bayes' theorem. The current form of Bayes theorem appeared in posthumously published Thomas Bayes' paper (1958), *An Essay towards solving a Problem in the Doctrine of Chances*. It was for solving the inverse probability shown in de Moirve's book (1756), *The Doctrine of Chances*. Inverse probability refers to the posterior probability, that is, to retrieve the causes from the effects or observations. The use of such probability was intended to improve person's decision making.

In his essay, Mr. Bayes started with the problem itself:

> *Given* the number of times in which an unknown event has happened and failed: *Required* the chance that the probability of its happening in a single trial lies somewhere between any two degrees of probability that can be named.

The proof of this problem is well known conditional probability form:

$$P(B|A) = \frac{P(A \cap B)}{P(A)},$$

where A and B are events. Since then, Bayes' theorem has been in used for more than two hundred years. However, the Bayesian probability interpretation is more recent, which is a measure of a state of knowledge (Jaynes, 2003). Some of well-known subjectivists are Frank Ramsey, Bruno de Finetti, and Leonard J. Savage. Subjectivists think a probability as the degree of belief which an individual has in a proposition or as state of knowledge of the real world (Waston and Buede, 1987).

Measurement of subjective probability is not trivial as Waston and Buede (1987) assert:

> To apply this calculus in other situations, however, requires more than an act of faith. What is needed is a set of assumptions about an individual's judgments which, if satisfied, leads us to infer that a set of numbers must exist which describe that individual's perceptions of uncertainty; and, moreoever, that these numbers should be combined using the rules of the probability calculus to infer what numbers should be used to describe other uncertainties. (p. 32)

Savage (1954) proposed a measurement of subjective probability based on two main assumptions: (1) all alternative can be rank ordered and (2) sure-thing principle (Edwards, 1961). He then used Bayes' theorem to update the prior probability to get the posterior probability.

By using a subjective probability with utility, Savage (1954) proposed a series of the postulates for preferences. He proved that these postulates imply that one's preference is fully coincide with the ranking ordered by subjective expected utility, and concluded that a rational individual should make a decision so that SEU is maximized (Shafer, 1986); that is, a normative theory of decision making. Such a normative interpretation does not claim that real people will necessarily follow SEU theory; rather they *should* (Savage, 1972). Many of empirical studies found indeed real people did not obey the postulates of SEU theory.

Prospect theory was proposed by Kahneman and Tversky (1979) as an alternative to the expected utility theory. It, as a descriptive theory of rational choice, attempted to explain the empirical violation of expected utility theory. Prospect theory is different from expected utility theory by:

> ... its hypothesis that individuals are risk-averse with respect to gains and risk-acceptant with respect to losses and for its emphasis on the importance of the actor's framing of decisions around a reference point. (Levy, 1992, p. 171)

Foundations of prospect theory include:

1. Values of outcome are expressed by either gain or loss from a reference point.
2. Individual is risk averse with gains and risk acceptant with losses.
3. Loss has a bigger impact than gain.
4. Framing of choice and identification of a reference point is important.

In prospect theory, there are two phases in choice process: editing and evaluation. In the editing phase, a problem is structured, such as identification of alternatives, identification of a reference point, and calculation of gain and loss for each consequence. In the evaluation phase, the value of the prospect of each alternative is calculated, and the one with the highest prospect is selected. Prospect V is calculated in a similar way in which expected utility is calculated:

$$V = \Sigma w(p_i) * v(x_i)\,,$$

where p is probability of obtaining outcome x, $w(p)$ is the probability weighting function and $v(x)$ is the value function. The value function incorporates the behavioral pattern found in the empirical findings of Kahneman and Tversky (i.e., the foundations listed above). The probability weighting function is the objective probability, but it not linear function of the latter. In fact, the values of this function are not probabilities. Tversky and Kahneman (1986, p. S257) recognized that the editing phase is often influenced by the "norms, habits, and expectancies of the decision maker"; therefore, there would be big individual differences among individuals, which would result in unpredictability in decision making. Because of this reason, Tversky and Kahneman focused more on the problems, in which behavior was mainly determined by evaluation phase (Levy, 1992). Therefore, formulation of the value function and probability weighting function are one of their main contributions in prospect theory. The findings of prospect theory, which are essentially based on the empirical test results of utility theory, taught us that people perceive and solve problems differently than expected utility suggests (Schoemaker, 1982).

Decision analysis (e.g., Raiffa and Schlaifer, 1961) is another model for a decision makings under risk. It is similar to other rationality models in that it relies on subjective probabilities and utility of alternatives, as Keeney (1982) asserts:

> "Philosophically, decision analysis relies on the basis that the desirability of an alternative should depend on two concerns: the likelihoods that the alternative will lead to various consequences and the decision maker's preferences for those consequences. Decision analysis addresses these concerns separately and provides the logic and techniques for integrating them." (p.828/829)

However, decision analysis is more application focused than other theories of a rational choice. It provides a framework to find the best alternative in the face of problem complexity, multiple objects, preferences of multiple decision makers, etc. Ultimately, the purpose of decision analysis is to help a decision maker to make a better decision by providing more insight and promoting creativity (Waston and Buede, 1987). Another important difference between decision analysis and other models of rational choice is that the decision analysis can handle dynamic decisions, such as sequential decisions.

Decision analysis starts with identification of alternatives and their consequences. Next, judgment of probability of consequences are determined, that is, subjective probability. Then, objectives and preferences of decision makers are identified, and based on these, utility function is formulated. Finally, expected utility of each alternative is calculated and the alternative with the highest expected utility is selected as the best choice.

Many (expected utility theory, SEU theory, and decision analysis) of the surveyed theories in this section are used as a normative and/or descriptive model of human decision making. They assert that a rational individual should follow the model of the rational choice theory. However, finding the best alternative whose expected utility is the highest is not an easy task to carry out. Indeed, violations of such models have been observed too many times. Simon (e.g., Simon, 1955, 1956) acknowledged the limitation of human mind and proposed the theory of bounded rationality. In the following sections, we will review the concepts of strict (or unbounded) and bounded rationality.

2.1 Strict rationality

A strictly (or unboundedly) rational decision maker is equipped with complete certainty about the world, or knowledge of full probability distributions of uncertain events, and with an ability to carry out complex calculations (Simon, 1955). Further, an unboundedly rational man has no limitations whatsoever; there is neither time limit nor cost concern, which allows unlimited deliberation and search. Many behavioral and cognitive models have been developed based on unbounded rationality (hereafter rational models). Examples include subjective utility theory for choice, exemplar models for categorization, multiple regression for judgment, Bayesian models for problem solving, and neural network for almost everything (Gigerenzer and Goldstein, 1999).

The rational models can predict how an unboundedly rational man will behave, and to do so, one needs to study only the task requirements or environment to which a decision maker must adapt his task requirements (Simon, 1979, 1990). This is because an unboundedly rational man is assumed to know everything and to be able to do anything in an environment. Simon (1990) provided an analogy of this argument:

> If we wish to know what form gelatin will take when it solidifies, we do not study the gelatin; we study the shape of the mold in which we are going to pour it. (p. 6)

Here, gelatin can form any shape (i.e., no limitation) to fit the mold. Further, it will form the same shape every time whenever it is poured into the same mold. Similarly, an unboundedly rational man will always behave the same way under the same environment and task requirements.

An outcome of, or solution to, a rational model is found by optimizing a goal of a decision maker with respect to the decision maker's (simplified) environment in the model. Optimization means to "maximize or minimize some explicit and measurable criterion (e.g. profits, errors, time) *conditional on certain environmental assumptions and a specified time horizon*" (Einhorn and Hogarth, 1981). Rational models will always make many assumptions to simplify complex real world environments, and the optimality of the models is conditional on the environmental assumptions (Simon, 1979).

The supporters of the rational models as a norm of behavior often argue that not following such models will result in a sub-optimal choice, and those who make a sub-optimal choice will not survive (Conlisk, 1996). Many empirical studies of human behavior have revealed that humans do not follow the rational models very often; that is, they do not make optimal choices (e.g., Tversky and Kahneman, 1974; Laville, 2000). Such deviations from the rational models are called errors or biases. According to these studies of the rational models, humans "appear nightmarishly irrational and dysfunctional in comparison" with the norm of unbounded rationality (Todd and Gigerenzer, 2000). However, humans have adapted to their environment successfully since the beginning of history without such rational models.

Along with the unrealistic assumptions of human capability, empirical findings of violations of the rational models raise a serious doubt on the normative role of these models. One thing to note is that the rational models have never been designed to describe how a decision is made as Simon (1979) put it:

> Notice that the refutation of the theory has to do with the substance of the decisions, and not just the process by which they are reached. It is not that people do not go through the calculations that would be required to reach the SEU [subjective expected utility] decision – neoclassical thought has never claimed that they did. What has been shown is that they do not even behave as if they had carried out those calculations, and that result is a direct refutation

> of the neoclassical assumptions. (p. 507)

That is, a move to reject the idea of using the rational models as a norm of behavior was not because they described the decision making process as optimization (i.e., rational calculation).

To respond to the criticism given to the rational model, some limitations (e.g., cost of information search and deliberation) were imposed on a decision maker in rational models, which was expected to make the rational models more realistic. However, these supposedly improved models were still based on unbounded rationality, and so they faced similar criticisms as the pure rational models did (i.e., the models with no limitations on a decision maker). Gigerenzer and Todd (1999) considered such models with additional assumptions to be even more complex than the pure rational models.

Recently, McKenzie (2003) suggested that rational models are just theory; not standard of behavior. This is because no compelling evidence has been found, which observes that human behaviors must be corrected according to the outputs of rational models. He summarized as follows:

> The reason, in a nutshell, is that errors in the laboratory often appear to be the result of strategies that in fact work well outside the laboratory. (p.403)

With lack of the rational models' abilities of either describing or satisfactorily predicting the human decision process, other models were investigated. As Simon (1979) said in his lecture at the reception of the Nobel Prize, "You can't defeat a measure or a candidate simply by pointing to defects and inadequacies. You must offer an alternative." As an alternative to unbounded rationality, bounded rationality was proposed.

2.2 Bounded rationality

Bounded rationality is about the reasoning of actual finite human minds and the environment in which the minds operate (Simon, 1956; Todd and Gigerenzer, 2003). With the realistic capability of the human mind, the act of optimization is not humanly possible. Therefore with bounded rationality, the question is not how to make an "optimal" choice. Rather, the question is how to make a "satisfactory" (or good enough) one given the limitations of time, knowledge, and computational capacity (Simon, 1955). As a result, under the assumption of bounded rationality, it is unlikely that people behave as if they carried out rational calculation or optimization. This is an important notion in that biases (or errors) under the rational models may disappear or be reduced in the models of bounded rationality (i.e., heuristic models). Consequently, the models of bounded rationality are said to be in "closer agreement with the facts of behavior as observed in laboratory and field" (Simon, 1956).

As a model of bounded rationality, Simon (1955) proposed the "satisficing" model of decision making. It is a heuristic method of finding a satisfactory solution when alternatives are sought sequentially. By satisficing, a decision maker chooses an alternative that is good enough rather than optimal, as in the models of traditional unbounded rationality. A decision maker will stop searching as soon as the outcome of choosing a certain alternative exceeds a personal "adjustable aspiration level," which may change from point to point in the sequence of alternatives (Simon, 1955). By using the method of satisficing, a decision maker does not need to search for all the alternatives, nor does he have to calculate the expected utility of each alternative. An aspiration level can be set by prior experience or by information acquisition.

Two key concepts of the theory of bounded rationality, and the heuristic models, are limited search and satisficing (Simon, 1979). A decision maker cannot do an exhaustive search (for alternatives, information or both) due to search costs and limited time: hence a limited search. Further, a decision maker will not deliberate endlessly due to deliberation costs, but will resort to a good enough (or satisfactory) solution or choice, which is satisficing. These two concepts are what allow the heuristic models to make a satisfactory decision with reasonable amounts of calculation (i.e., not optimization) based on incomplete information (Simon, 1979).

With bounded rationality, heuristics, not optimization are the tools for making a satisfactory choice. According to *The American Heritage Dictionary of the English Language, Fourth Edition*, heuristic, as an adjective form, means: "Of or relating to a usually speculative formulation serving as a guide in the investigation or solution of a problem." This definition implies the guiding role of heuristics in the process of decision making. Gigerenger and Goldstein (1996) consider a heuristic a useful shortcut, approximation, or a rule of thumb for: (1) a guiding search for alternatives and/or information, (2) for stopping search, and (3) for decision making. Many different methods of guidance (i.e., heuristic models) can exist, which differ in search methods, stopping rule or decision rule. Different (satisfactory) outcomes can be produced based on what heuristic models are used, even in the same environment. Simon (1979) points out this possibility and stresses the importance of making a descriptive model of the decision process as follows:

> ... rather conclusive empirical evidence that the decision-making process in problem situations conforms closely to the models of bounded rationality ... implies ... that choice is not determined uniquely by the objective characteristics of the problem situation, but depends also on the particular heuristic process that is used to reach the decision. It would appear, therefore, that a model of process is an essential component in any positive theory of decision making that purports to describe the real world, and that the neoclassical ambition of avoiding the necessity for such a model is unrealizable. (p. 507)

This also suggests that there could be many heuristics in a decision maker's repertoire. This idea is further discussed in the next section.

The main difference between the research of unbounded and bounded rationality is the standard of being rational; whether or not being rational should be determined based on how satisfactory decision making outcomes are in a real world environment, but not based on how closely the outcomes follow some optimal models. It is suggested that the norm of rational decision making under bounded rationality should be adaptiveness to a real world (Gigerenzer and Goldstein, 1996); that is, the performance of decision making should be measured by how *ecologically* rational (i.e., good enough in real world environments) it is (Gigerenzer and Goldstein, 1996). In next section, specific heuristics built on the idea of being ecologically rational are discussed.

2.3 Ecological rationality

> "How can one be rational in a world where vision is limited, time is pressing, and decision-making experts are often unavailable?" (from preface, Gigerenzer et al., 1999)

It is a typical situation that agents with bounded rationality (i.e., we) face in a real world. In such an environment, searching for an optimal solution would not be wise, since it is generally not knowable. Rather, searching for an adaptive solution in a quick and cost-effective manner would be wiser. The latter solution is the heart of ecological rationality. That is, ecological rationality is about making adaptive decisions to physical and social environments in a fast and frugal way, in which a boundedly rational decision maker resides.

Ecological rationality is built based upon the notion of bounded rationality. That is, the study of ecological rationality acknowledges the limitations of the actual human mind as well as the important role of the environment to which a decision maker must adapt. However, the study of environments has been much neglected in mainstream cognitive sciences, including the research of bounded rationality (Gigerenzer and Todd, 1999). Research in ecological rationality scrutinizes the role of an environment in decision making.

An external environment imposes two constraints on the decision mechanism of an agent whose rationality is bounded (Todd et al., 2000). The first is the simplicity of a mental mechanism. We never encounter exactly the same environment twice, and this uncertainty requires a mental mechanism to be simple so that the mechanism can effectively generalize to a new, but similar, environment. The second is quickness and frugality of the mechanism. Environments are often time pressing and competitive, which in turn requires an agent to make a decision fast, and in a cost-effective way. Fast and frugal heuristics are tools to achieve ecological rationality by exploiting the environmental structure while embracing the two constraints.

Social rationality is a special form of ecological rationality. It is about making an adaptive interaction between decision makers. Besides fast and frugal heuristics, social norm, emotion, and social imitation can act as heuristic principles to make socially rational decisions. It is important to study social rationality because the most important aspects of an agent's environment are often created by interactions with other agents (Todd and Gigerenzer, 2000).

2.3.1 Fast and frugal heuristics

Ecological rationality represents a pure form of bounded rationality, and fast and frugal heuristics represent a pure form of a mental mechanism of a boundedly rational agent (Gigerenzer et al., 1999). This statement is based on two arguments. First, fast and frugal heuristics employ a minimum of time, knowledge, and computation (even less than the Simon's satisficing model). Second, they take advantages of an environmental structure to make adaptive choices in a real world with a frugal search for alternatives, information or both. The fit between heuristic and an environmental structure is called ecological rationality of a heuristic and is what causes the fast and frugal heuristics to be very accurate in spite of the frugal use of resources (Martignon and Hoffrage, 1999; Martignon and Hoffrage, 2002). The premise of the ecological rationality is that "... much of human reasoning and decision making can be modeled by fast and frugal heuristics." (Gigerenzer and Todd, 1999, p. 6)

Many fast and frugal heuristics have been proposed for different cognitive tasks and environmental structures where the proposed heuristics are ecologically rational. These environmental structures are found through mathematical analysis and simulations (Gigerenzer et al., 1999). The collection of fast and frugal heuristics is called an adaptive toolbox of the decision maker (Gigerenzer and Todd, 1999).

One reason decision making is used for choice between two alternatives without estimation. In the classical view of rationality, when people make a decision, they use all available cues to make the decision. On the contrary, one reason decision making relies on only one cue to make a decision, even if the cue is imperfect. An imperfect cue means that the probability of choosing correct alternative is not one, when a decision is made based on such a cue that discriminate two alternatives. One reason decision making is fast, because it neither has to search for many pieces of information nor has to calculate/combine multiple pieces of information. One reason decision making is frugal, because it uses only one piece of information that discriminates two alternatives. A family of one reason decision making heuristics includes recognition heuristic, minimalist heuristic, take-the-last (TTL) heuristic and take-the-best (TTB) heuristic.

The recognition heuristic is the simplest form of one reason decision making and uses only one piece of information – recognition, which is "essentially binary feeling that we have or have not experienced something before" (Goldstein and Gigerenzer, 1999). The recognition heuristic can be stated as follows. If only one of two alternatives is recognized, then choose the recognized alternative as a correct answer to a certain criterion (e.g., faster, higher, stronger). Besides partial recognition or ignorance (i.e., recognizing only one of two alternatives), correlation (either positive or negative) with a criterion is required for the recognition heuristic to work. For example, for the criterion of higher population, the recognition of cities is positively correlated to the criterion; that is, a recognized city often has a higher population than an unrecognized one.

The minimalist, TTL and TTB heuristics all have a similar form as follows, and their difference lies with step 2:

Step 1. Use of recognition heuristic

Step 2. Search for a cue that discriminate two alternatives

Step 3. Stop search as soon as a cue discriminating two alternatives is found

Step 4. Make a decision based on the cue found in step 3

If only one alternative is recognized in the first step, then make a decision; if both are recognized, then go to step 2; if neither is recognized, then guess. In step 2, the minimalist heuristic employs a random search for a cue that discriminate two alternatives. The TTL employs an ordered search, which is based on the knowledge (or memory) about which cue was successful to discriminate alternatives in earlier tasks.

> For the first problem, Take the Last tries cues randomly like the Minimalist, but from the second problem onward it starts with the cue that stopped search the last time. If this cue does not stop search, it tries the cue that stopped search the time before last, and so on. (Gigerenzer and Goldstein, 1999)

The TTB heuristic employs an ordered search based on cue validity.[1] Once a cue that discriminates two alternatives is found, all of the three heuristics stop the search and make a decision based on that cue.

The characteristics of the environment in which these one reason decision making heuristics work well include non-compensatory information and scarce information (Gigerenzer and Goldstein, 1996). Non-compensatory information refers to the environment where each cue is more important than any combination of less valid cues (Martignon and Hoffrage, 1999).[2] Graphical representation of non-compensatory cues is shown in Figure 2.1. Another example is the alphabetical order used in a dictionary.[3] If the first letters in two different words are different, then the rest of the spellings in these words does not matter in determining the order between the two. Scarce information refers to the environment where the number of binary cues available is less than that required to describe (or code) alternatives uniquely and unambiguously (Martignon and Hoffrage, 1999). For example, four objects can be coded uniquely by using two binary cues; if the number of cues available is one, then this environment provides scarce information.

[1] See section 2.4

[2] For a mathematical analysis, see appendix B.

[3] See also 2.4.

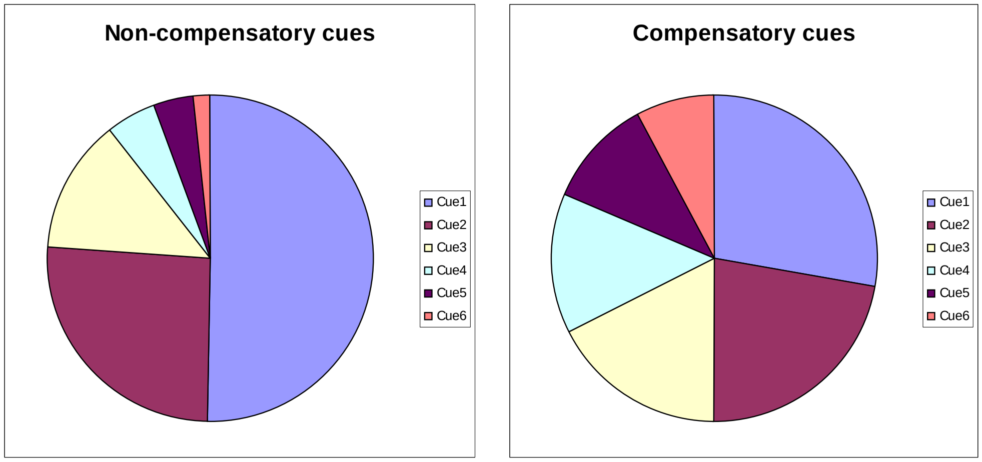

Figure 2.1: Compensatory vs. non-compensatory information

Even though the school of ecological rationality considers (fast and frugal) heuristics as an essential tool to achieve an adaptive decision, the school of the heuristics-and-biases program lead by Tversky and colleagues discounts the value of heuristics by considering them as a cause of biases in decision making. Tversky and Kahneman (1974) define heuristic as a mental rule of thumb that helps "… reduce the complex tasks of assessing probabilities and predicting values to simpler judgmental operations." They acknowledge the usefulness of heuristics in general, but warn that sometimes their use can result in systematic departures from the norm (i.e., bias). Due to these biases, Tversky and others consider a heuristic as a flawed rule of thumb. The biases are measured by comparing observed behavior with the outcomes of the rational model(s). As said earlier, however, it has been argued that using the rational models, such as the subject utility theory, as the norm of sound human decision making may be flawed (e.g., Gigerenzer et al., 1999), because such norms ignore the bounded rationality of human mind.

Both the fast and frugal heuristics and the heuristics-and-biases program recognize the usefulness of heuristics (Simon, 1956; Kahneman and Tversky, 1979; Simon, 1979; Gigerenzer et al., 1999). A difference arises from the answer to the question, "what is a standard of rational human decision making?", as Todd et al. (2000) summarizes as follows:

> ... [Research on ecological rationality] shares common foundations with the heuristics-and-biases research programme in looking for the simple shortcuts that people actually use to make decision, but differs by building precise models of environment-exploiting heuristics that work well according to ecological, and not just logical, norms. (p.383)

That is, the standard against which the performance of heuristics is measured is the key difference between the fast and frugal heuristics and the heuristics-and-biases program.

2.3.2 Performance of fast and frugal heuristics

Hammond (1999) argues that there are two different performance criteria for decision making: correspondence and coherence. Correspondence measures decision-making strategies related to the external world; such as speed, frugality, and simplicity, while coherence is about the internal consistency of decision making.

For preference based decision making, coherence criteria are often used as a performance measure. This is because when decisions are based on personal preference, there are no external criteria for determining whether or not the response is right (Pitz and Sachs, 1984); that is, correspondence criteria cannot be used. For inference based decision making, both coherence and correspondence criteria can be used.

To be rational, according to the normative rational models of preference or inference, the responses should be consistent with one another. (Pitz and Sachs, 1984; Vriend, 1996). The responses should not be changed based on irrelevant factors related to, for instance, context or mode of presentation (Shafir and LeBoeuf, 2002). That is, coherence criteria are used for measuring performance of the models of unbounded rationality. The proposed fast and frugal heuristics in the series of work by Gigerenzer and colleagues are for inference based decision making. The performance of fast and frugal heuristics is measured by the correspondence criteria, not by coherence ones. This is because ecological rationality is about performing adaptively in the real-world, which is closely related to correspondence criteria.

Gigerenzer and colleagues (e.g., Czerlinski et al., 1999) compared the performance of the rational models and that of the proposed fast and frugal heuristics based on real-world criteria, such as the proportion of correct inference. Note that the rational models are not the standard to which fast and frugal heuristics are compared. If they were, by definition, the heuristic models could never be more accurate than the rational models (Todd et al., 2000). However, when the real-world criteria are introduced, ecologically-rational heuristics can outperform the rational models. For data-fitting task, the fast and frugal heuristics work as well as most of the rational models, and for generalization (i.e., prediction) task, the fast and frugal heuristics work even better than the rational models in some environments.

2.3.3 Empirical validation of fast and frugal heuristics

One of the most important challenges to the research of fast and frugal heuristics is an empirical validation; that is, to check whether people indeed use fast and frugal heuristics. For the empirical validation of the heuristics, Todd et al. (2000) suggest that:

> The metaphor of the adaptive toolbox ... encourages a methodology that is sensitive to the existence of multiple heuristics and individual differences in their use. (p. 774)

This is due to the belief that each individual can have a different adaptive toolbox. This also implies that there may not be an environment in which TTB is exclusively used by all participants due to their individual differences. This leads to another important question to be validated empirically – how are heuristics selected from the adaptive toolbox?

Gigerenzer and Todd (1999) propose that specificity of heuristics, knowledge of an environment, and other external factors can help to determine which heuristic should be used for a certain task. Specificity of heuristics means that each family of heuristics is designed to do a certain task. For example, the TTB heuristic is designed to work for inference-based choice tasks and will not be used for categorization tasks. If more than one heuristic is available for a task, then the knowledge of the environment that a decision maker faces may help. For example, without knowing the validities[4] of cues in an environment, an agent cannot use the TTB heuristic; the TTB heuristic requires the knowledge of cue validities in order to be of use. That is, the TTB heuristic is not an ecologically rational heuristic for a decision maker who does not know the validities. Finally, external factors, such as time pressure, past success, and adaptive reasons, may affect the choice of heuristics from the adaptive toolbox.

Most empirical studies (Bröder, 2000, 2003; Newell et al., 2003; Newell and Shanks, 2003) have tested the idea of the fast and frugal heuristics and adaptive toolbox; that is, whether people indeed use the fast and frugal heuristics. These studies focus on the use of the TTB heuristic, which will be discussed in details in next section.

2.4 Lexicographic heuristic and Take-The-Best heuristic

In this paragraph, we will introduce the concept of a "lexicographic order" and explain it briefly. Without loss of generality, let each of two alternatives x and y be described by multiple characteristics or cues that are ordered by a certain criterion. Then, each of the characteristics of x is compared to each of those of y in an orderly fashion: from the first cue to the last cue. If a characteristic whose values for x and y are different is found and the value of this characteristic for x precedes that for y, then x precedes y lexicographically (Fishburn, 1974). Because of this reason, a lexicographic order is also known as an order by the first difference (Hausdorff, 1957). The alphabetical order of words is considered to be the prime example of the lexicographic order (Fishburn, 1974), such as the order used in an English dictionary. For example, "ski" precedes lexicographically "skin." Both words can be described by four characteristics as follows: ski = (s, k, i, ϕ) and skin = (s, k, i, n). Then, the fourth characteristic (i.e., ϕ and n) differs, and ϕ precedes n. Therefore, "ski" precedes "skin" lexicographically.

[4]See section 2.4

The lexicographic order can be applied to the model of preference or choice tasks (e.g., Duncan et al., 1953). Alternatives can be evaluated by multiple criteria and can be ordered lexicographically based on these criteria. For example, three cities – A, B, and C – are considered for the place of living, and they are evaluated based on three criteria – crime rate, pollen count, and living cost. The values of each criterion for each city are shown in Table 2.1.

City	Crime rate	Pollen count	Living cost
City A	Low	Medium	High
City B	Low	Low	High
City C	Medium	Low	Medium

Table 2.1: An example for the lexicographic decision rule

The first criterion to consider is the crime rate, the values of the crime rate of city A and B are the same, and both of them are better than that of city C. Since city A and B are tied, the second criterion, the pollen count, is considered for these two cities. Between city A and B, city B has a lower pollen count; therefore, B is better than A, followed by C. Therefore, city B is the best place for living based on the lexicographic decision rule, or the *lexicographic heuristic*. Note that the order of criteria to consider is often determined by the importance of each criterion for a decision maker. If the order is changed, then we may have a different lexicographic order of the cities and thus a different answer to the question. For example, if the first cue to be considered is living cost, then the best city for living is city C. Therefore, the order of criteria to be considered for a decision making plays an important role in the lexicographic heuristic, and it is related to the 'validity of cues' explained later in this section.

As a special case of the lexicographic heuristic, Gigerenzer and colleagues coined the term the take-the-best heuristic. The TTB heuristic is used in a pair-wise comparison for finding the best alternative for a certain criterion based on an imperfect cue (or pieces of information) regarding the alternatives. The alternatives are lexicographically ordered based on values of the cues. The main differences between the lexicographic decision making rule and the TTB heuristic are: (1) the use of the recognition heuristic by the latter heuristic and (2) the number of alternatives involved in the task (i.e., multiple in the lexicographic decision rule vs. two in the TTB heuristic).

The recognition heuristic in the TTB heuristic works when only one of two alternatives is recognized, and a decision maker should choose one that he/she recognizes as an answer to the inference task. For example, for the question "Which city has a larger population? (a) Hamburg (b) Cologne," if a decision maker recognizes Hamburg but not Cologne, then he/she should choose Hamburg to answer the question. If both alternatives are recognized equally, then cue(s) or information will be searched (from the memory). If neither alternative is recognized, a decision maker is supposed to guess (Gigerenzer and Goldstein, 1996). This is because when neither alternative is recognized, cues or information related to either alternative cannot be retrieved from memory. This implies that the TTB heuristic is for the memory-based inferences; that is, information or cues are searched from memory. However, the TTB algorithm can easily be applied to the situation where information is searched externally. In such a case, it is possible to use the TTB heuristic even when neither alternative is recognized.

By the TTB heuristic, cues are searched in the order of their *ecological validity* (Gigerenzer and Goldstein, 1996). When two alternatives are compared based on a certain cue, the ecological validity of this cue refers to the relative frequency of the comparisons in which cue values are associated accurately with a correct answer, out of all possible comparisons, in which cue values for two alternatives differ; that is, "the proportion of right inferences" (Martignon and Hoffrage, 1999, p. 130). Therefore, ecological rationality can be written as follows:

$$v = \frac{R}{R+W}, \tag{2.1}$$

where R is the number of right inference and W is the number of wrong inference. Note that one can make an inference base on a cue only when a value of this cue is different for two alternatives. If the cue values are the same, this cue does not have predictive power in that comparison. When the validity is expressed in terms of probability, it is the probability that one's inference based on a certain cue is correct given an inference can be made based on the cue. In other words, the validity is the probability that a cue will identify an alternative correctly given its cue value is different for two alternatives. That is,

$$v = P(\text{right inference} \mid \text{cue values differ for two alternatives})\,.$$ [5]

Consider an example shown in Table 2.2. The task is to select a city with a larger population. A sample of five cities is considered for this example: Houston (TX), Phoenix (AZ), Boston (MA), Columbus (OH), and Omaha (NE). The order of cities based on a population is:[6]

$$\text{Houston(TX)>Phoenix(AZ)>Boston(MA)>Columbus(OH)>Omaha(NE)}\,.$$

The cue used in this example is 'MLB city,' that is, does this city have a major league baseball team? The value of the cue is binary (Yes or No), and we assume that a city with a MLB team (i.e., a value of the cue is Yes) has a larger population than a city that does not have a MLB team. The first column in Table 2.2 is a comparison number i from 1 to 10. The second and the third column contain names of cities in a comparison. The fourth and the fifth column show a cue value for each city. Finally, the cities in shaded cells represent the correct answers (i.e., a city with larger population).

The cue does not discriminate the cities in the comparison 1, 2, 5 and 10. That is, one cannot rely on the cue, MLB city, to infer which city has a larger population in these four

[5] The validity is expressed in the form of likelihood here based on the definition of Gigerenzer and others (See appendix C). However, a more correct form of validity should be

$$P(\text{cue favors alternative } i \,|\, \text{alternative } i \text{ is correct \& cue value is not tied}).$$

Values of these two probabilities are the same under the special condition of experiments including current study.

[6] http://www.infoplease.com/us/census/top-50-cities-2006.html

comparisons. Therefore, a total number of comparisons in which the cue has different values for the cities is six. Out of these six comparisons, the cue value is associated correctly with a city with a larger population in five comparisons (i = 3, 4, 6, 7, 9). Therefore, the ecological validity of the cue, MLB city, in this example is 5 out of 6 or 0.833 (i.e., the proportion of right inferences).

i	City 1	City 2	MLB in city 1	MLB in city 2
1	Houston, TX	Phoenix, AZ	Yes	Yes
2	Houston, TX	Boston, MA	Yes	Yes
3	Houston, TX	Columbus, OH	Yes	No
4	Houston, TX	Omaha, NE	Yes	No
5	Phoenix, AZ	Boston, MA	Yes	Yes
6	Phoenix, AZ	Columbus, OH	Yes	No
7	Phoenix, AZ	Omaha, NE	Yes	No
8	Boston, MA	Columbus, OH	Yes	No
9	Boston, MA	Omaha, NE	Yes	No
10	Columbus, OH	Omaha, NE	No	No

Table 2.2: An example of validity

If the validity is expressed in terms of probability, it is

$$P(\text{population of city 1}>\text{population of city 2} \mid \text{city 1 has a MLB team, but not city 2}). \quad (2.2)$$

Note that the order of city (i.e., city 1 and city 2) in each comparison is arbitrary, and this order does not affect the calculation of the validity. That is, even if the values of the second and the third columns in Table 2.2 are swapped and those of the fourth and fifth columns are swapped, the value of the validity will be the same. Therefore, probability 2.2 is the same as the following probability,

$$P(\text{population of city 1}<\text{population of city 2} \mid \text{city 2 has a MLB team, but not city 1}).$$

Using more general notations, the following statement is true for a two-alternative case:

$$P(\text{A is better}|\text{a cue favors A, but not B}) = P(\text{B is better}|\text{a cue favors B, but not A}).$$

Note that A and B do not represent any meaningful concepts. They simply denotes the first and the second alternative, and *any* value can be the first and the second alternative.

Cues are searched from the one with the highest validity to the one with the lowest validity by the TTB heuristic. If two alternatives have the same value for the cue with the highest validity, the cue of the next highest validity will be evaluated until the values of a cue differ for the alternatives. Validities of cues can be known genetically or learned. In the case of learning, the order of cues (i.e., cue hierarchy) can be estimated from the relative frequency with which they predict the criterion. Note that the cue hierarchy used in the TTB heuristic does not have to be optimal (by incorporating dependencies between cues) or perfectly accurate; rather, it is a frugal (or good enough) ordering (Gigerenzer and Goldstein, 1996). Such a frugal order can be estimated from a small sample of objects and cues.

The TTB heuristic stops the search for cues as soon as the selected cue discriminates alternatives; that is, the cue values of two alternatives are not tied. Its motto is "take the best, ignore the rest" (Gigerenzer and Goldstein, 1999). It intentionally ignores other possibly existing cues; hence a non-compensatory decision rule. A decision is made based on the values of a non-tied cue. In summary, the TTB heuristic consists of three building blocks: the ordered information search, the stopping rule, and the decision rule.

Out of the three rules of the TTB heuristics (i.e., search, stop, and decision rule), the stopping rule bears the most importance in distinguishing fast-and-frugal strategies (e.g., the TTB heuristic) from some compensatory ones (Newell et al., 2003). Simon (1979) recognized the importance of a limited search in the models of bounded rationality, and Gigerenzer & Goldstein also stressed the importance of the stopping rule as they put: "Lim-

Figure 2.2: Classification map of decision strategies

ited search is a central feature of fast and frugal heuristics..." (Gigerenzer and Goldstein, 1999, p. 77). Even if the (TTB) search rule is violated, a strategy can still be considered to be a one-reason decision making heuristic as long as the stopping rule is supported. However, as soon as the stopping rule is violated, the strategy used will become non-one-reason decision making strategies, such as semi-compensatory strategies (e.g., weight of evidence) and compensatory strategies (e.g., equal weight linear rule). This argument is summarized in 2.2.

Simple heuristics such as the TTB heuristic that ignores intentionally other possibly existing cues and thus avoids possible conflicts were often considered to be irrational, because they look "stupid" in comparison to traditional norms of unbounded rationality (Gigerenzer and Goldstein, 1999). However, the performances of the TTB heuristic and of other fast and frugal heuristics have been shown, through mathematical models and simulations, to be as good as or better than some compensatory models of unbounded rationality, such as a multiple regression model (Czerlinski et al., 1999). This is because the performance of the fast and frugal heuristics are measured against real world environments (i.e., correspondence criteria), not against some rational models. Such good performances of the fast and frugal heuristics were attributed to the ecological rationality of the heuristics. The TTB heuristic is ecologically rational in the environment with non-compensatory information[7] and is as good as or better than the rational models that use all cues in such an environment. Counterintuitive results of more-accurate-with-less-information contributed to the recent popularity of the fast and frugal heuristics in theoretical and empirical research.

2.5 Empirical studies of the TTB heuristic

In this section, we will briefly review and summarize three recent papers relevant to this dissertation. These papers test the use of the TTB heuristics empirically. Foci in each review are research objectives, dependent variable(s), experimental setting, and the findings of the studies.

2.5.1 Experiments by Bröder (2000)

Bröder (2000) tested TTB's adequacy as a descriptive model of human probabilistic inference through four experiments. In this section, we will review two experiments that are relevant to to current sttudy.

2.5.1.1 Experiment 2 [pp. 1340-1341]

This experiment was designed to test a weak version of a TTB hypothesis: some participant would use the TTB heuristic in an experiment. Specifically, more people will use the TTB heuristic under the condition of high cue dispersion than under that of the low cue dispersion. The dependent variable of this study is the proportion of TTB users, which was captured by administering the regression-based classification procedure. Appendix A provides a detailed explanation of this classification procedure. Based on the literature (e.g., Payne et al., 1993), the author states that people's strategy selection is a result of an adaptation to specific contexts. If that is the case, the proportion of TTB users will vary

[7] See page 20

under different context conditions in which the TTB heuristic is more or less appropriate.

The cover story told participants of forty students that they were future researchers doing a study on extraterrestrial ethnology on the distant plant Viltvodl VI. Their task was to judge the degree of civilization of different cultures based on four cues and to choose an object from two alternatives that they believed to score higher on a hypothetical criterion. Cue values were presented simultaneously at no cost in each trial. Cue dispersion was manipulated as a between-subject factor: low vs. high. A low dispersion group had validities of .90, .82, .74, and .66,[8] and .96, .82, .68, and .54.[9] In the learning phase, participants went through 50 trials for each cue for a total of 200 trials, in which approximate cue validities could be learned. After the learning period, participants completed 120 decision trials.

Across the both conditions, 11 of 40 participants were classified as TTB users in this experiment (4 (20%) in low cue dispersion condition and 7 (35%) in high cue dispersion condition). From this finding, the author concluded that the TTB heuristic played an important role in explaining the human inference procedure. However, the proportion of TTB users was not significantly different for low and high cue dispersion conditions. That is, cue dispersion was not a factor that promoted better use of the TTB heuristic. The author suggested that a more extreme variation of cue dispersion would be desirable in future study. One thing to note is that to detect the medium sized hypothesized effects (Cohen's (1988) effect size index $w = .3$) of the context conditions with a small sample size (40 participants), Type I and II error levels of .24 were used in this experiment as well as in experiment 3. The test of difference between the proportions of TTB users in two conditions was done by a chi-squared statistic.

2.5.1.2 Experiment 3 [pp. 1341-1342]

This experiment focused on the effect of the cost of information. The hypothesis tested was that more people will use the TTB heuristic when the cost of information is high than when

[8]These cue validities represent compensatory information.

[9]These cue validities represent a strictly non-compensatory information.

the cost of information is low. As in experiment 2, the dependent variable of this study is the proportion of TTB users.

The cover story for experiment 3 was completely different from that of the experiment 2. The participants in this experiment were told to imagine that they were stock brokers working for a bank. Their task was to pick a stock that they thought was the more profitable of two alternatives (i.e., stock prediction task). Four binary cues (i.e., yes/no) with semantic labels were used:

1. Was the share trend positive over the last months?
2. Does the company have financial reserves?
3. Dose the company invest in new projects?
4. Is it an established company?

Validities of the cues are .80, .75, .70, and .69.[10]

The cost of information was manipulated; each cue costs 10 Penunzen (a virtual currency paid by virtual employers) in the low cost group and 100 Penunzen in the high cost group. In the high cost condition, the overall expected payoff across the 120 trials using the TTB heuristic were greater than that using a weighted additive model (WADD); in the low cost condition, a WADD strategy yielded a higher expected payoff than the TTB heuristic.[11] That is, the high cost condition favors the TTB heuristic; the low cost condition favors a WADD.

Once the procedure of the stock market game was briefly explained (e.g., how to buy a cue), participants went through 120 paired comparisons of all 16 cue patterns. The cues can only be purchased sequentially by the order of their validities: from the most valid to the least valid cue. Once participants chose a stock in each trial, the probability that the chosen stock was the most profitable was calculated according to Bayes rule assuming conditional independence of the cues and was shown on the screen. Based on the calculated probability, a random number generator determined the most profitable share. If participants were

[10]These cue validities represent a compensatory information.

[11]How the weights of WADD were determined was not specified in the original article.

correct, 1000 Penunzen were paid. All the invested costs on cues were deducted from private accounts of participants.

The findings suggested that a high information cost better promoted the TTB heuristic: 13 TTB users (65%) in the high cost condition and eight (40%) in the low cost condition. The chi-squared test statistic $\chi^2_{(1)} = 2.51$ and the p-value is 0.113. The author conclude that the numbers of TTB users are significantly different for low and high information cost conditions.[12] However, inter-individual differences in strategy selection still existed. That is, some participants used a WADD under the high cost condition, and some participants used the TTB heuristic under the low cost condition. The authors concluded that the strategy selection was not only imperfectly adaptive to an environment but was also influenced by idiosyncratic preferences for strategies.

2.5.2 Experiments by B. Newell and Shank (2003)

B. Newell and Shank (2003) tried to solve some of the questions that had been raised in Bröder's experiments. First, can participants learn the relative order of cues if the order is not provided directly? Second, if participants can learn the relative order, will they buy information based on the learned order and stop buying information after a non-tied cue? Third, can we have more knowledge about a substantial proportion of participants who kept buying cues (i.e., compensatory strategies, for example, equal weight linear rule) after they discovered a non-tied cue (i.e., violators of the TTB stopping rule)? To study these questions, B. Newell and Shank created three experiments by using an adapted form of Bröder's (2000) stock prediction task (i.e., experiment 3), and in this section, we will review two experiments.

The methodology used for studying the issues mentioned above was a process-oriented approach, rather than Bröder's regression-based classification procedure. Using the process-oriented approach, three key aspects of participants' behavior were closely monitored,

[12] Type I error level used in the study was 0.24. See page 32.

which were:(1) the number of cues bought in each trial, (2) the order in which cues were bought, and (3) whether or not cues were bought after discovering a non-tied cue. Note that the second and third aspects are related to the TTB information search rule and TTB stopping rule, respectively.

The analysis of data was done in a group level as well as in an individual level. In the group level analysis, the mean number of cue bought and the proportion of trials in which the stopping rule was followed were used as dependent variables. Particularly, the latter was of higher interest to the authors. The TTB heuristic was analyzed in the individual level; first, each participant was classified as a TTB user or non-TTB user, and then the number of TTB users was used as a dependent variable.

2.5.2.1 Experiment 1 [pp. 55-57]

This experiment was designed to test whether people can learn the relative order of cues based on their validities (i.e., cue hierarchy). Further, the experiment tested whether higher relative information cost better promoted the TTB heuristic. These objectives were tested based on the participants' behavioral data captured during the experiment.

The experimental settings are the same as those of experiment 3 by Bröder (2000) with following exceptions. The cues can be purchased in any order, and 60 trials of a learning phase were provided. Relative cost of information was manipulated through the different amount of payoffs. In the high relative cost group, if participants were correct in each trial then they were paid five pence minus one penny per cue viewed. In the low relative cost group, if participants were correct in each trial, they were paid ten pence minus one penny per cue viewed.

The group level analysis results suggested that more information was bought in the low relative cost group. Mean numbers of cues bought per trial were 1.36 in the high relative cost group and 2.54 in the low relative cost group. The proportions of trials in which the TTB stopping rule was violated were lower in the high relative cost group (0.15) than in the low relative cost group (0.64); the difference in proportions for two groups was significant (F(1,15) = 26.33, p-value < .001) This pattern seems to suggest that the TTB heuristic was used more often in the high relative cost condition. However, this pattern can be misleading because information was searched mostly randomly in both conditions. In the individual level analysis, only one participant (13%) out of 8 in the high cost condition and zero participants (0%) out of 8 in the low cost condition could be classified as the TTB user.

Based on the findings, the authors concluded that participants had difficulties in establishing and searching through a subjective rank order of cues. This result highlighted the difficulty that the participants had in leaning a cue hierarchy.

2.5.2.2 Experiment 2 [pp. 58-59]

Essentially, experiment 2 was a replication of the high relative cost condition of experiment 1. The main difference between them was the hint about cue hierarchy that was given to the participants in experiment 2. The objective of this experiment is to assess participants' behaviors more accurately in the individual level analysis. The hint of cue hierarchy was provided after 30 trials in a learning phase and at the beginning of a decision phase.

This hint implied, for example, that knowing whether a company has a positive share trend was more useful in making a correct prediction than knowing whether the company has financial reserves and so on. The hint of cue hierarchy included all the four cues, and the same hint was used both times (Personal communication with Dr. B. Newell, 2007).

In the group level analysis, the mean number of cues bought per trial (2.39) and the proportion of trials in which the TTB stopping rule was violated (0.44) was higher in experiment 2 (i.e., with the hint) than in the high cost condition of experiment 1 (i.e., no hint but with learning phase). The authors provided one possible explanation for such increases as follows:

> ... providing participants with the hint about the usefulness of the information implied that all pieces of information had some value and were thus worth buying.

Overall, about 33% (4 out of 12) of the participants was classified as TTB users. These results showed that there were still a lot of variations in the strategy selection despite the hint.

2.5.3 Experiments by B. Newell, Weston, and Shank (2003)

The aim of these experiments was to find an environment in which previously observed TTB violations in the experiments by B. Newell and Shank (2003) were eliminated or reduced. Methodology and experimental settings used in these experiments were very similar to those used in the experiments by B. Newell and Shank (2003). As in the experiments of B. Newell and Shank (2003), analysis was done in a group level as well as in a individual level.

2.5.3.1 Experiment 1 [pp. 84-89]

Based on the findings of process-tracing studies, the authors argued that increasing the number of available cues (from four to six) would make an environment more complex, which in turn would induce a simpler decision strategy. The authors were particularly interested in whether or not more participants followed the TTB stopping rule in this experiment than in experiment 2 by B. Newell and Shank (2003).

The task for the participants in the experiment was the stock prediction task, which is similar to the task used in Bröder (2000) and B. Newell and Shank (2003). Six binary cues were available, and each of them could be purchased at one penny. They were:

1. Was the share trend positive over the last few months?
2. Does the company have financial reserves?
3. Does the company invest in new projects?
4. Is it an established company?
5. Is the company listed on the FTSE?
6. Is the employee turnover low?

The validities of the cues are 0.90, 0.85, 0.80, 0.75, 0.70, and 0.65.[13] The six cues and two alternatives provided 2016 possible unique paired comparisons, out of which 180 comparisons were randomly selected. If the participant's answer was correct, in each trial, they gained seven pence minus one penny for each cue viewed. In the case of a wrong answer, there was neither gain nor loss. There was no learning phase, but the hint about a cue hierarchy was given after 60 trials and again after 120 trials. The way the hint was given was very similar to the way used in experiment 2 by B. Newell and Shank (2003). Data for the analysis was collected from the last 60 trials.

In a group level, the proportion of trials in which the TTB stopping rule was violated was 0.20, and the proportion of trials in which the decision rule was violated was 0.11. Individual level analysis results indicated that the percentage of TTB users (33%, 8 out 24) in this experiment did not significantly increase from the experiment 2 performed by B. Newell and Shank (2003). That is, increasing the number of available cues did not promote the use of the TTB heuristic better.

2.5.3.2 Experiment 2 [pp. 89-91]

This experiment was a replication of experiment 1 but with only two cues instead of six and with a different payoff amount. The authors reasoned that the simplicity of the environment, due to the low number of available cues, would reduce the temptation for participants to buy another piece of information after finding a non-tied cue. The two cues provided were:

1. Does the company invest in new projects?
2. Is it an established company?

Validities of the cues were .80 and .60.[14] The two cues provided 12 possible unique comparisons. Each comparison was repeated ten times in a different random order for each

[13] These cue validities represent a compensatory information.
[14] These cue values represent a non-compensatory information.

participant for a total of 120 trials. If the participant's answer was correct, in each trial, they gained five pence minus one penny for each cue viewed. In the case of a wrong answer, there was neither gain nor loss. The hint regarding a cue hierarchy was provided once after 30 trials. Data for analysis was collected from the last 30 trials.

In a group level, the proportion of trials in which the TTB stopping rule was violated was 0.11, and the proportion of trials in which the decision rule was violated was 0.11. In a individual level, thirty three percent (8 out of 24) of the participants were classified as TTB users, and the majority (16 out of 24) of the participants employed the frugal stopping rule – either TTB or Take-One. Take-One heuristic refers to the rule by which subjects bought only the most valid cue and made a decision regardless of whether the first cue was tied or not. That is, they guessed whenever the first cue was tied.

After a series of the experiments, B. Newell and colleagues concluded that the TTB heuristic (more generally fast-and-frugal heuristics) is yet to be validated empirically. They suggest that the TTB heuristic is employed by only a small proportion of people and thus psychological reality is either doubtful or that the authors are looking in the wrong place for conditions that encourage the use of the TTB heuristic.

2.5.4 Summary table

Experimental settings of the reviewed experiments are summarized in Table 2.3, and the analysis results are summarized in Table 2.4.

	EX	Task	Infor. cost	# of cue	cue validity	Infor. presentation	# of trials	Learning or hint
Broder 2000	ex2	To judge the degree of civilization of different cultures based on five cues and to choose an object from two alternatives	free	4	Comp. in low Non-comp. in high	Simultaneous	120	Learning
	ex3	To pick a **stock** that they thought was the more profitable of two alternatives	not free	4	comp	Forced sequential	120	None
Newell 2003	ex1	the same as above	free when wrong	4	comp	Any order	120	Learning
	ex2	the same as above	free when wrong	4	comp	Any order	120	Hint
Newell et al. 20003	ex1	the same as above	free when wrong	6	comp	Any order	180	Hint
	ex2	the same as above	free when wrong	2	comp	Any order	180	Hint

Table 2.3: Summary of experimental settings

	EX	Factor of interest	How	DV	Value of DV	Hypothesis	Finding
Bröder 2000	ex2	Cue dispersion	manipulating cue dispersion (low vs. high)	Proportion of TTB user	Low: .20 High: .35	Low < High	Not supported
	ex3	Information cost	manipulating info cost (low vs. high)	Proportion of TTB user	Low: .40 High: .65	Low < High	Supported
Newell 2003	ex1	Information cost	manipulating info cost (low vs. high)	Proportion of TTB user	0.13	Low < High	Not supported
				Prop. Stopping rule followed	0.85	Low < High	Supported
	ex2	Knowledge of cue hierarchy	Cross-comparison with ex1.high	Proportion of TTB user	0.33	Exploratory	
				Prop. Stopping rule followed	0.56	Exploratory	
Newell et al. 20003	ex1	High complexity of environment	Cross-comparison with ex2 by Newell and Shank	Proportion of TTB user	0.33	Exploratory	
				Prop. Stopping rule followed	0.8	Exploratory	
	ex2	Low complexity of environment	Cross-comparison with ex1	Proportion of TTB user	0.33	Exploratory	
				Prop. Stopping rule followed	0.89	Exploratory	

Table 2.4: Summary of analysis results

Chapter 3

Research Objectives

Several empirical studies (Bröder, 2000; Newell et al., 2003; Newell and Shanks, 2003) were done to test the question "Do people use the take-the-best (TTB) heuristic in inference tasks?" The empirical findings suggest that the answer is yes, but not consistently. That is, some participants in the experiments used the TTB heuristic, while others did not. These findings are in line with the metaphor of the adaptive toolbox, which allows the possibility of the existence of multiple heuristics in the toolbox and of individual difference in the selection of heuristics.

These empirical findings lead to another important question; "How are heuristics selected?" or more specifically "When is the TTB heuristic more *likely* to be used?" In the current study, I want to investigate three related research questions dealing with the role of ecological and social rationality in how people go about making a decision. First, I want to test whether people use the TTB heuristic more often in a non-compensatory environment than in a compensatory environment. Second, I want to find out whether people use the TTB heuristic more often in the condition of high information cost than in the condition of low information cost. Third, I want to test whether people use the TTB heuristic more often when doing so does not go against the social rationality as opposed to when it does. I will build these research questions by pointing out some important but neglected aspects of the prior experiments concerning the TTB heuristic.

3.1 Research question 1

Bröder (2000) tested (in experiment 2) the effect of cue dispersion (i.e., compensatory vs. non-compensatory environment) on the use of the TTB heuristic. He hypothesized that people's strategy selection was a result of an adaptation to specific contexts. As a result, the proportion of TTB users would be greater in a non-compensatory environment than in a compensatory environment, because the TTB heuristic works best in a non-compensatory environment (Martignon and Hoffrage, 2002). However, he did not find supporting evidence of this hypothesis. That is, the proportions of TTB users in two environments were statistically the same. From this test, one may conclude that people are not adaptive to their environment. However, based on this result alone, we cannot abandon the adaptivity assumption, especially when the experimental environment was not good enough for testing such an assumption. We explain the deficiencies of his experiment for testing the adaptivity assumption.

In Bröder's (2000) experiment, if a random number generator determined the correct choice based on the probability calculated according to the Bayes rule assuming conditional independence of the cues, oursimulation of 1000 experiments shows that the TTB heuristic is a better decision strategy in non-compensatory environment as expected. The mean accuracy of the TTB heuristic in the non-compensatory environment is 84% and that of the equal weight linear rule (EWL) is 73%. That is, the TTB heuristic outperforms the alternative by 11% in terms of mean accuracy in the non-compensatory environment. Interestingly, the TTB heuristic also outperforms EWL in the compensatory environment. The mean accuracy of the TTB heuristic in the compensatory environment is 80% and that of EWL is 76%. Therefore, the TTB heuristic was a better strategy not only in the non-compensatory environment but also in the compensatory environment. All in all, the TTB heuristic seems to be an adaptive and ecologically rational strategy in both environments. That is, in Bröder's (2000) experiment, both environments favor the TTB heuristic. In such environments, the difference in the proportions of TTB users might not be statistically significant.

Further, in Bröder's experiment the four cues were provided simultaneously at no cost. That is, the participants did not need to search for or spend money for the cues. In his paper, Bröder himself points out that the most influential environmental characteristic for promoting the use of the TTB heuristic is the successive *purchase* of cues. Therefore, with the condition of free information, not many participants are expected to employ the TTB heuristic.

B. Newell and colleagues provide indirect insight regarding the plausibility of adaptivity assumption through the series of experiments. B. Newell and Shank (2003) created an experimental environment (experiment 2) that strongly promotes the use of the TTB heuristic by having four non-free cues and providing a hint regarding a cue hierarchy. They found that about half of participants did not use the TTB heuristic. Later, by increasing the number of available cues from four to six, B. Newell et al. (2003) tried to reduce the previously observed TTB violations in the experiments of B. Newell and Shank (2003). However, they found that the number of cues did not impact greatly the strategy selection. B. Newell et al. (2003) conducted another experiment using only two cues, and the results suggested that frugal information search and acquisition was employed more often compared with the prior experiments of B. Newell and Shank (2003) and with the first experiment of B. Newell et al. (2003). Therefore, based on these results, participants seem to favor frugal information acquisition methods in the environments with a smaller number of cues. However, we will test whether such findings can be contributed to the information structure (i.e., compensatory vs. non-compensatory) of environments in the experiments, which in turn can explain participants' adaptive behavior.

As mentioned earlier in section 2.3.3.1, validities of the cues in B. Newell et al.'s (2003) experiment 1 are 0.90, 0.85, 0.80, 0.75, 0.70, and 0.65. These values indicate that the information structure in the experiment is compensatory.[1] That is, each cue can be outweighed

[1] see Appendix B for more discussion.

by the combination of less valid cues. For example, the most valid cue can be outweighed by the combination of the second and the third most valid cues. This is an important aspect of the experiment, which B. Newell et al. failed to mention in their study. The participants in the experiment may have experienced (many) trials in which the alternative favored by the most valid cue was not the correct answer. Therefore, the participants may have wanted to buy more cues to increase the confidence in their answers. As a result, the TTB heuristic may have not been used in the experiment by some participants. On the contrary, the environment of B. Newell et al.'s experiment 2 is non-compensatory. In such an environment, the TTB heuristic is an ecologically rational choice, and thus the TTB stopping rule was violated less compared with experiment 1. Therefore, in sum, it can be said that people are indeed adaptive to an environment, at least in the experiments.

As can be seen, from the past experiments, the effect of cue dispersion on decision strategy selection is not clear. In this paper, we propose to test the effect of cue dispersion (i.e., compensatory vs. non-compensatory information structure) on the selection of decision making strategy with the condition of non-free information.

> **Hypothesis 1:** The proportion of TTB decision in a non-compensatory structure is greater than that in a compensatory structure.

3.2 Research question 2

From the findings of the prior experiments, the cost of information seems to be one of the most dominant factors that affect decision strategy selection (Bröder, 2000). There were two experiments in which the difference in the use of TTB was tested in the conditions of a low and high information cost: Bröder's (2000) experiment 3 and B. Newell and Shank's (2003) experiment 1. The results of these two experiments are conflicting; the former study found that high cost condition favored the TTB heuristic better, and the latter study found the proportion of TTB users was not significantly different for low and high cost conditions.

However, we argue that their conclusions are weak due to the reasons explained below and that a re-test of the effects of information cost is required.

In Bröder's (2000) experiment 3, 8 out of 20 participants (40%) were classified as a TTB user in the low cost condition, and 13 out of 20 (65%) participants were classified as a TTB user in the high cost condition. The chi-squared test statistic for testing the significance of the difference between these two proportions was $\chi^2_{(1)}$=2.51, and its p-value was 0.113. Since significance was tested at $\alpha = 0.24$ in the original paper, the difference was considered to be significant. However, if the significance had been tested at a more conventional α level (i.e., 0.05), then the difference would would have been insignificant. Bröder himself recognized such a weakness of his findings as he put:

> Obviously, conclusions about the hypotheses are preliminary, given these large error probabilities. ... Even if the conclusion drawn from one experiment is "soft" with respect to statistical error probabilities, the replication of effects in further experiments can serve as a confirmation of their existence. (pp. 1339-1340)

Later, B. Newell and Shank (2003) replicated (in experiment 1) Bröder's experiment 3 with similar experimental settings: (1) low vs. high relative information cost and (2) no learning phase. The authors found that the TTB stopping rule was supported better in the high cost condition; 4 out of 8 participants followed the TTB stopping rule in the high relative cost condition, and 1 out of 8 participants followed the TTB stopping rule in the low relative cost condition. Most participants lacked the knowledge about cue hierarchy due to the absence of a learning phase. As a result, the TTB search rule was violated in a large degree in both conditions. Since a TTB user is someone who follows the search, stopping, and decision rule, the participants who follow the stopping rule but violate the search rule cannot be classified as a TTB user. Among the five participants who followed the stopping rule, only one participant in the high relative cost condition was classified as a TTB user. Therefore, the question of whether high information cost promotes the TTB heuristic better than low information cost is not clearly answered in this experiment.

Descriptive statistics from B. Newell and Shank's (2003) experiment 1 shows that overall a higher degree of frugality in terms of information purchase was achieved in the high relative cost condition. The mean numbers of cues bought were 1.36 in the high relative cost condition and 2.54 in the low relative cost condition; the difference was significant at $\alpha = 0.05$. The mean proportions of the trials in which the TTB stopping rule was followed were 0.85 in the high cost condition and 0.36 in the low cost condition; the difference was significant at $\alpha = 0.001$. These patterns are in line with a common belief that less information would be purchased if the cost is higher. Therefore, with the knowledge of cue hierarchy, we argue that the TTB heuristic will be used more often under the condition of high perceived cost of information rather than low perceived cost of information.

> **Hypothesis 2:** The proportion of TTB decision in a high perceived cost condition is greater than that in a low perceived cost condition.

3.3 Research question 3

One contrasting figure to homo economicus is homo sociologicus, whose behavior is dictated by social norms (Elster, 1989). Homo sociologicus is "insensitive to circumstances, sticking to the prescribed behavior even if new and apparently better options become available" (Elster, 1989). There are many definitions for social norms, but commonly defined, it is "social attitudes of approval and disapproval, specifying what ought to be done and what ought not to be done." (Sunstein, 1996). Further, such norms "are also sustained by the feelings of embarrassment, anxiety, guilt and shame that a person suffers at the prospect of violating them" (Elster, 1989). The existence of social norms in a situation can therefore affect the choice of a decision strategy. A decision maker may choose a certain strategy to avoid an uneasy feeling associated with violating social norms, even if such a strategy results in inferior results. In the current study, the definition of social norms is in line with one given by Larson (1977):

> Social Norm: An expected pattern of behavior appropriate in a given situation. (Gibbs, 1981, pp. 8)

The participants of the B. Newell et al.'s experiments (and of others with a similar task) experiments may have been influenced by the demand characteristic (or artifact) of the experiments. Orne (1969) commented on the demand characteristic as follows:

> Insofar as the subject cares about the outcome, his perception of his role and of the hypothesis being tested will become a significant determinant of his behavior. The cues which govern his perception – which communicate what is expected of him and what the experimenter hopes to find – can therefore be crucial... They include the scuttlebutt about the experiment, its setting, implicit and explicit instructions, the person of the experimenter, subtle cues provided by him, and, of particular importance, the experimental procedure itself. *All of these cues are interpreted in the light of the subjects' past learning and experience.* Although the explicit instructions are important, it appears that subtler cues from which the subject can draw convert of even unconscious inference may be still more powerful. (Quoted in (Sawyer, 1975), emphasis added)

If the participants had bought stocks or heard about the stock purchase before, such experiences could have interfered with the behaviors of the participants. When people decide on which stock to buy, they generally rely on more than one piece of information (e.g., Herrmann, 2007); such a tendency can serve as a social norm. That is, buying more than one cue is socially rational for stock purchase, and the participants are expected to buy more than one cue. Additionally, in their review article on the assumptions about biases, Mellers et al. (1998) say that "Subjects often have other concerns, not known to the experimenter" to convey that a rational choice may differ between an experimenter and subjects. Such an argument can be applied to the experiments of B. Newell et al. That is, while the experimenters (e.g., B. Newell) knew that the TTB heuristics (or the TTB stopping rule) would do very well in finding a correct answer, the participants did not know that and, as a result, followed the social norm (i.e., buying more than one cue) hoping to find a correct answer.

With social rationality, emotion, social norms, and social imitation can act as the heuristic principles. That is, any of three factors above can guide information search, stopping search, and decision making. If the participants believed that using only one cue to find a more profitable stock is dumb based on social norms or imitation, then using more than one cue is a socially rational decision. In addition, as said earlier, using non-compensatory strategies that rely on only one cue to make a decision may look “stupid” (Gigerenzer and Goldstein, 1999). All in all, an argument of demand characteristics and social rationality suggest that why B. Newell et al.’s (and other’s) stock prediction task cannot provide an environment in which the violation of the TTB heuristic would have been minimized.

Bröder (2000), who first used the stock prediction task to test the use of the TTB heuristic, also recognized a similar notion of social rationality in his experiment 1 and 2 as he put:

> … an artificial environment was created in order to minimize possible interference from preexisting knowledge that might distort learning … (p. 1336)

However, his experiments 1 and 2 employed the environment of free information and simultaneous display of cue information, which may have prohibited the use of the TTB heuristic. Nevertheless, Bröder did not investigate further the possibility that the stock prediction task might be influenced by the participants’ social rationality.

> **Hypothesis 3:** The proportion of TTB decision is greater when it not opposed by social rationality than when it is opposed by social rationality.

Chapter 4

Methodology

Research in cognitive process of decision making involves two potentially complementary methodologies: a structural (or statistical) modeling approach and process modeling approach (Ford et al., 1989; A. Newell, 1972). In structural models, statistical models are built based on observed independent (i.e., stimuli) and dependent variables (i.e., decision outcomes), and inference regarding underlying cognitive process will be drawn. What happens, or what people do, between the introduction of stimuli and decision outcomes are not observed in structural models. The regression-based classification method (e.g., Bröder, 2000) is more closely related to structural models than it is to process models.

Process models, on the other hand, actively observe what happens between the introduction of stimuli and decision outcomes. An example is "thinking aloud" protocol used by A. Newell (1972), by which participants speak loudly what they think during tasks. A basic idea of process models is that what happens during a decision making process has to be collected as often as possible and then analyzed as important data (Svenson, 1979). When a process modeling approach is employed, algorithm or strategies that people use to arrive at a decision are the main focus of inquiry (Ford et al., 1989). Therefore, in general a process tracing method would be a better way of testing algorithms involved in decision making than a structural modeling approach.

The processing tracing method used in B. Newell et al. (2003) is employed in this study, rather than the regression-based classification method used by Bröder. To use the latter method, participants must answer all the possible comparisons derived from the combinations of cues and alternatives in an experiment. In each of four experiments conducted in the current study, six cues were used to describe each of two alternatives, and there were 2016 possible unique paired comparisons in each experiment. Asking participants to go through 2016 comparisons is not practical.

Further, the test of the take-the-best (TTB) stopping rule requires an observation of what happens during a decision process, which requires knowledge of how many cues are viewed in each trial so that we can understand better how a decision is made (i.e., frugal vs. non-frugal). For example, if we know a participant viewed only one cue and made a decision, it can be expected that the decision was made based on that cue value. Typically, structural models cannot tell how many cues are viewed in each trial. As a result, a process-tracing method is used to test the hypotheses.

4.1 Experiments

4.1.1 Participants

A total of 146 undergraduate students in a south-eastern US university participated voluntarily in this study. Most of the participants were junior and senior students in business school. The numbers of subjects in the base case, treatment 1, treatment 2, and treatment 3 are 41, 26, 39, and 40, respectively. Each subject in the experiment underwent 180 trials. The total numbers of observations collected from each experiment are shown in Table 4.1.

Treatments	Subjects	Trials
Base case	41	7380
Non-compensatory (Treatment 1)	26	4680
Non-free information (Treatment 2)	39	7020
No-social norm (Treatment 3)	40	7200
Total	146	26280

Table 4.1: The number of participants in the experiments

An incentive of the participation is extra credits to a specific class that they attend. Even though the experiments utilize the payoff of dollars, there was no monetary compensation in the study. That is, the payoff that the participants saw in the experiments was funny money.

4.1.2 The base case – compensatory structure, free-information, social norm

The base case in this study, which will serve as a basis for testing significance of the hypothesized effects, is a replication of B. Newell et al.'s experiment with three modifications in the experimental settings. The original experiment by B. Newell et al. was conducted in United Kingdom, and thus, some of the experimental settings may not be familiar to the participants in United States. As such, the currency used in the experiment was first changed from pound (£) to dollar ($). Second, FTSE used in a cue description in the original experiment was replaced with Standard & Poor's (Investopedia, 2007). Third, the payoff structure – the beginning balance and payoff amount – was different; the beginning balance was $1000, and the payoff and cost were in dollars. A detailed description of the experimental environment and procedure is outlined below.

4.1.2.1 Experimental environment and procedure

The experiments were done through a simulation program built on Microsoft Visual Basic and were carried out on PCs with Microsoft Windows operating system. The participant's task was to choose the more profitable one between stocks from two fictional firms (Stock A and Stock B). They were also told that the goal of the experiment was to earn as much money as they could by choosing the more profitable stock. To help the participants' task, six binary (i.e., Yes or No) cues were available for purchase, which are listed below:

1. Was the share trend positive over the last few months?
2. Does the company have financial reserves?
3. Does the company invest in new projects?

4. Is it an established company?
5. Is the company listed on the Standard & Poor's?
6. Is the employee turnover low?

Validities of cues are 0.90, 0.85, 0.80, 0.75, 0.70, and 0.65, and these values are of *compensatory structure*. The compensatory structure refers to an environment in which the initial direction (or stock) pointed by a certain cue can become less likely to be a correct answer when all or some of less valid cues are combined. The positions of the cues on the screen were the same for all participants, but assignment of the validities to the six cues were counterbalanced among the participants.

The participants could buy up to six cues, and each cue cost a dollar ($1). All cues were presented on the screen at the same time without showing their values for each company. Once participants clicked a "Purchase" button right next to the cue, the values of the cue were shown (e.g., Yes for Stock A and No for Stock B). Once they chose a stock, the probability that the chosen stock was more profitable was shown, which was calculated according to the Bayes rule assuming the conditional independence of the cues. A random number generator then determined the more profitable stock based on the calculated probability. If the chosen stock was the more profitable one, a participant's private account increased by seven dollars minus one dollar for each cue viewed. If the chosen stock was not the more profitable one, their private accounts remained the same. That is, their private accounts did not decrease; in other words, the cue information was *free* when the answer was wrong. The beginning balance was $1,000. Screen layout of the simulation program is shown in Figure 4.1.

Participants went through three rounds of 60 trials. As in the original study (Newell et al., 2003), the participants were instructed that they should try to figure out which cues were the most useful in making correct predictions since not all cues were equally informative. A cue hierarchy based on the validity, similar to one given in experiment 2 of B. Newell and Shank (2003), was given to the participants at the end of the first round and again at the end of the second round. After 180 trials, participants were asked to fill out a

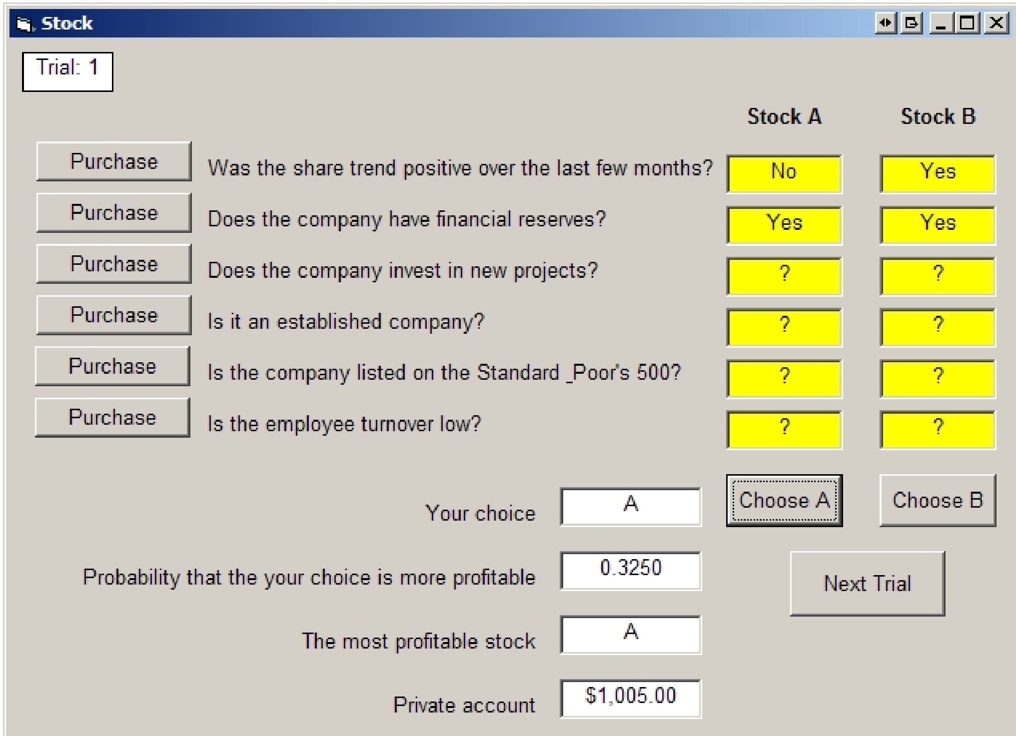

Figure 4.1: Screen layout of the program (In the screen shot, two cues are purchased.)

paper-based questionnaire, in which they rate the usefulness of each cue by using a number from 1 to 100. Since the probability of cue values being tied for the two alternatives is roughly 0.5 for all the cues, the usefulness rating will correspond to the predictive utility. A post-test questionnaire also asked participants to indicate the statement that best described the strategy that they used for information purchasing and that they used for making a decision based on the purchased cue(s).

4.1.3 Treatment 1 – non-compensatory information

In the experiment with non-compensatory structure, only the validities of the cues were different from the base case. Validities of the cues used in this experiment were 0.96, 0.83, 0.80, 0.52, 0.51, and 0.50, which represented a non-compensatory environment. The procedure of experiment with non-compensatory structure was exactly the same as that of the base case. Screen layout of this experiment was the same as that of the base case.

4.1.4 Treatment 2 – non-free information

The task environment for the experiment with non-free information was the same as that of the base case except that participants' private accounts could decrease. In this experiment, the cost of each cue was one dollar, and participants' private accounts decreased by one dollar as soon as they bought a cue. As in the based case, the participants could buy up to six cues in each trial. If the participants were correct, their private accounts increased by seven dollars. If they were wrong, then there was no payoff. That is, money spent for purchasing information was not recovered, when participants were wrong.

4.1.5 Treatment 3 – no social norm

The only differences between the base case and the experiment with no social norm were the stimulus used and the cue description provided. A "stock" in the base case was replaced with a "fish." The validities of the cues were the same as those of the cues in the base case (i.e., compensatory). The participants were asked to pick one, between two tropical fishes (Fish A and Fish B), that they thought was more profitable to breed and to sell to a pet store. Complete instructions for the base case and this experiment including six binary cues are shown in Table 4.2.

People read and hear many stories or tips, from newspapers, TV, friends, etc., about how to buy what stock. When they are exposed a great deal of information and the information is consistent, they will develop or learn a certain norm for stock purchase. On the contrary, not many people receive information regarding breeding a tropical fish; that is, the task in this experiment would be novel to most of the participants. In such a case, it is unlikely for the participant to have any social norm regarding the fish selection task.

	The base case (stock)	Treatment 3 (fish)
Task	To choose a **stock** (one of two alternatives) that you think turns out to be the more profitable	To choose a tropical **fish** (one of two alternatives) that you think turns out to be the more profitable **to breed and sell to pet stores**
Goal	To earn as much as you can by choosing the more profitable **stock**	To earn as much as you can by choosing the more profitable **fish**
Cues	To help your task, the following six cues are available for purchase: **1. Was the share trend positive over the last few months?** **2. Does the company have financial reserves?** **3. Does the company invest in new projects?** **4. Is it an established company?** **5. Is the company listed on the Standard & Poor's?** **6. Is the employee turnover low?** You can buy as many as six cues before making a decision. Once you buy a cue, the value of the cue for each **stock** will be revealed, which is either YES or NO.	To help your task, the following six cues are available for purchase: **1. Is it bright colored?** **2. Does it weigh more than 2 ounces?** **3. Is its tail longer than 1 inch?** **4. Is its back fin longer than ¼ inch?** **5. Is it an active fish?** **6. Is it shorter than 3 inches?** You can buy as many as six cues before making a decision. Once you buy a cue, the value of the cue for each **fish** will be revealed, which is either YES or NO.
Usefulness	Not all six cues are equally useful in terms of increasing the number of correct predictions. A hint regarding the usefulness of the cues will be given after the 60th trial and again after the 120th trial. There are a total of 180 trials.	Not all six cues are equally useful in terms of increasing the number of correct predictions. A hint regarding the usefulness of the cues will be given after the 60th trial and again after the 120th trial. There are a total of 180 trials.
Payoffs	Once you choose a **stock**: The probability that the chosen **stock** is the most profitable will be calculated and shown on the screen. When your choice is the more profitable: You will gain $7 minus $1 per each cue viewed. When your choice is not the more profitable: There is no gain or loss.	Once you choose a **fish**: The probability that the chosen **fish** is the most profitable will be calculated and shown on the screen. When your choice is the more profitable: You will gain $7 minus $1 per each cue viewed. When your choice is not the more profitable: There is no gain or loss.

Table 4.2: Comparison between the instructions of the base case and the experiment with treatment 3 (differences are written in bold fonts)

4.2 Variables

4.2.1 Independent variables

Independent variables for the analysis in this study are the treatments effects: information structure (i.e., compensatory vs. non-compensatory), information cost (i.e., free when wrong vs. not free), and social rationality (i.e., a social norm vs. no social norm)

4.2.2 Dependent variable for hypothesis testing

The hypotheses presented earlier study the effect of each treatment on the proportion of TTB trials. The dependent variable for testing the hypotheses is the proportion of TTB trials in the last 60 trials in each experiment. The TTB trials are those in which all of the search, stopping, and decision rule are followed. An illustration of the TTB trials is presented in figure 4.2[1,2], in which two cues are available. Each hypothesis in this paper is tested by comparing the proportion of TTB trials of the base case with that of each treatment case. The proportions of TTB trials are shown in Table 4.3.

	Non-TTB trials	TTB trials	Total
Base case	68.1%	31.9%	2460
Non-compensatory (Trt 1)	68.5%	31.5%	1560
Non-free information (Trt 2)	70.0%	30.0%	2340
No-social norm (Trt 3)	63.2%	36.8%	2400
Overall	67.3%	32.7%	8760

Table 4.3: Proportions of TTB trials

[1] Note that by the design of the experiment (in this example and the current study), there is at least one cue that is not tied in every trial.

[2] A (or B) coming before the vertical bar (|) is a participant's choice. A (or B) coming after the vertical bar indicates an alternative favored a cue. When two cues are purchased, the first letter and the second letter represent an alternative favored by the first cue and the second cue, respectively. The question mark, ?, indicates that cue values are tied. For example, A|AB means that the first cue and the second cue favor A and B, respectively; a participant chooses A.

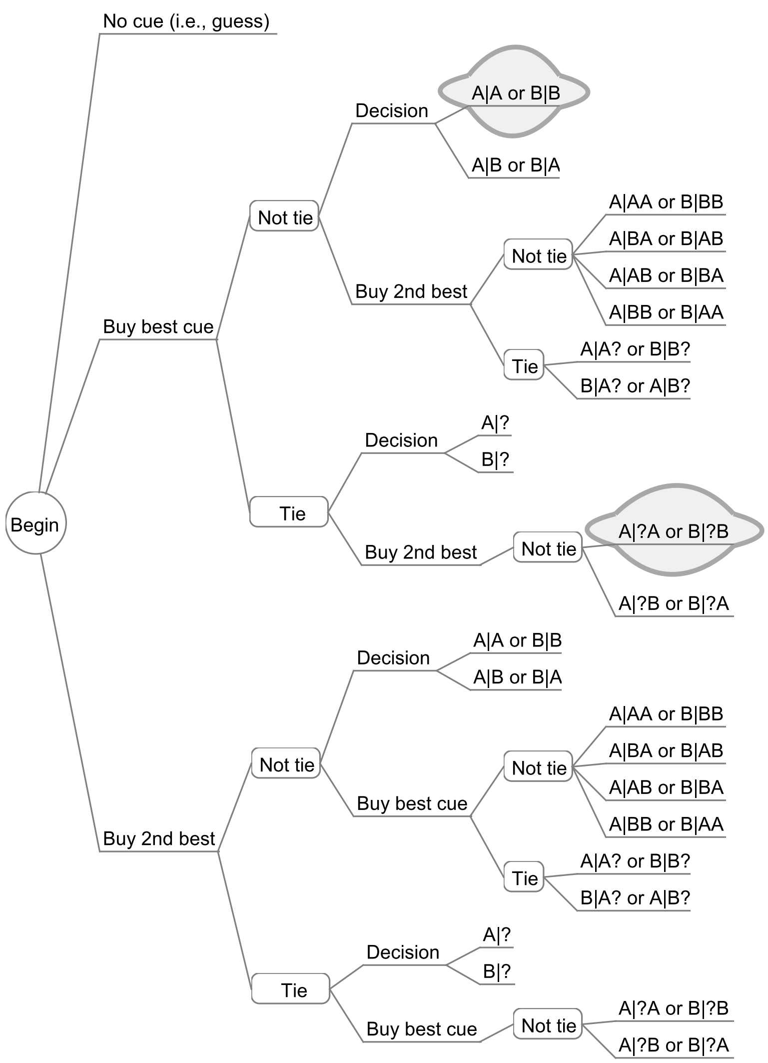

Figure 4.2: Illustration of TTB trials

4.2.3 Dependent variables for additional analysis

Besides tests of hypothesis proposed in this study, the effect of each treatment on the three rules (or building blocks) of the TTB heuristic is analyzed.

4.2.3.1 TTB search

For the calculation of the proportion of trials in which the search rule was followed, trials in which no information was purchased at all (i.e., complete guess) were excluded. The proportions of excluded trials, those of trials in which the search rule was violated (i.e., non-ordered search trials), and those of trials in which the search rule was followed (i.e., ordered search trials) are shown in Table 4.4. Note that this variable does not tell whether other rules (i.e., the stopping rule and the decision rule) are followed; it only tells whether or not cues are purchased in the order of their validity given some cues are purchased. An illustration of the trials with the search rule is shown in Figure 4.3.

	Excluded trials	Non-ordered search	Ordered search	Total counts
Base case	11.4%	35.2%	53.3%	2460
Non-compensatory (Trt 1)	6.3%	50.2%	43.5%	1560
Non-free information (Trt 2)	9.7%	38.8%	51.5%	2340
No-social norm (Trt 3)	7.8%	41.8%	50.5%	2400
Overall	9.0%	40.7%	50.3%	8760

Table 4.4: Proportions of ordered search trials

4.2.3.2 TTB stop

For analyzing the stopping rule, only the trials in which the first cue was tied were considered. Then, the trials were classified into three groups: trials in which some pieces of information were purchased but all were tied (i.e., early stop); trials in which the stopping rule was followed (i.e., TTB stop); trials in which more information was purchased after the first non-tied cue (i.e., late stop). Illustrations of the three stopping rules are presented

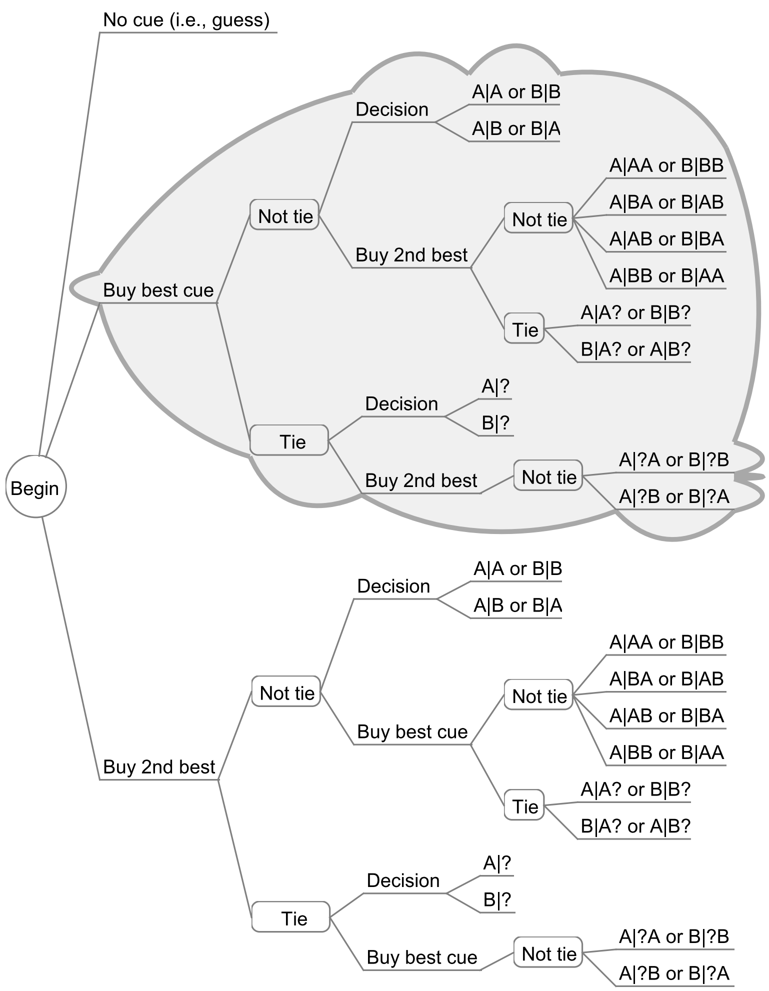

Figure 4.3: Illustration of the search rule

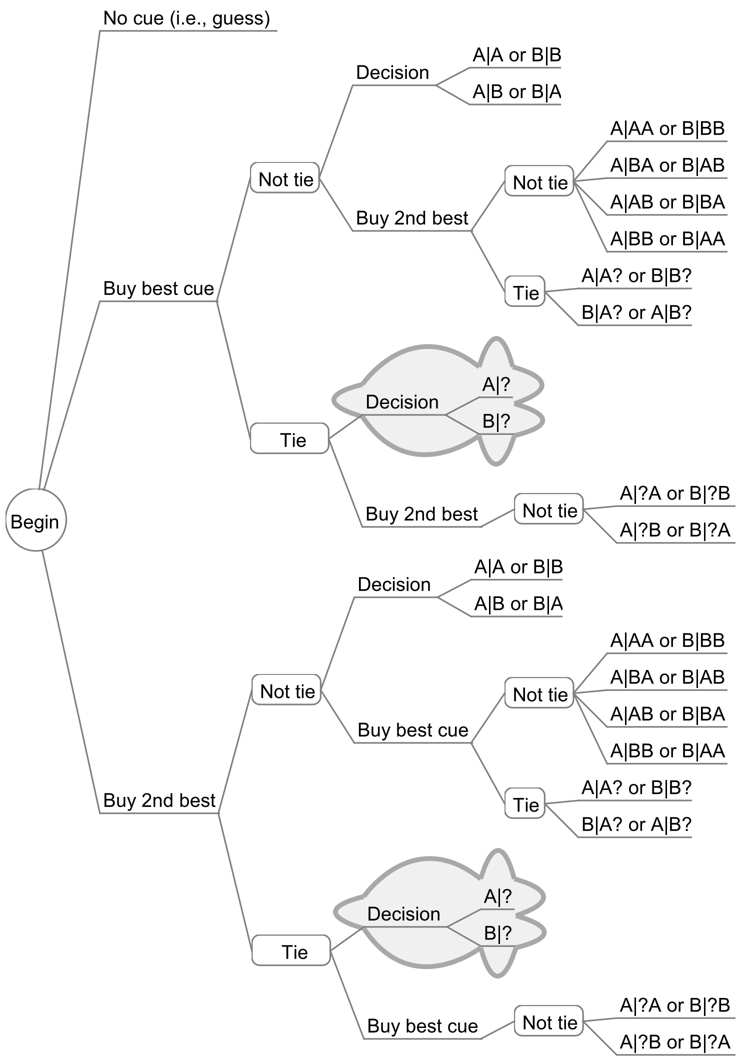

Figure 4.4: Illustration of Early stop

in figures 4.4, 4.5[3], and 4.6[4], the proportions of each group are shown in Table 4.5.

The reason for using the trials in which the first cue is tied is that if the first cue bought is not tied, then the participants could make either TTB stop or late stop, but not early stop; the proportion of early stop trials would be deflated. Therefore, by eliminating the trials in which the first cue bought was not tied, we can examine the behavior of the participants who could have chosen any of three stopping rules: early, TTB and late stop.

[3]The clouds with the cross mark represent the trials with the TTB stop by definition. However, since the first cue is not tied, they are not included in the analysis.

[4]The clouds represent the trials in which the late stop is used. However, since the first cue bought is not tied, they are included in the analysis. In the environment with two cues, it is not possible to use the late stop.

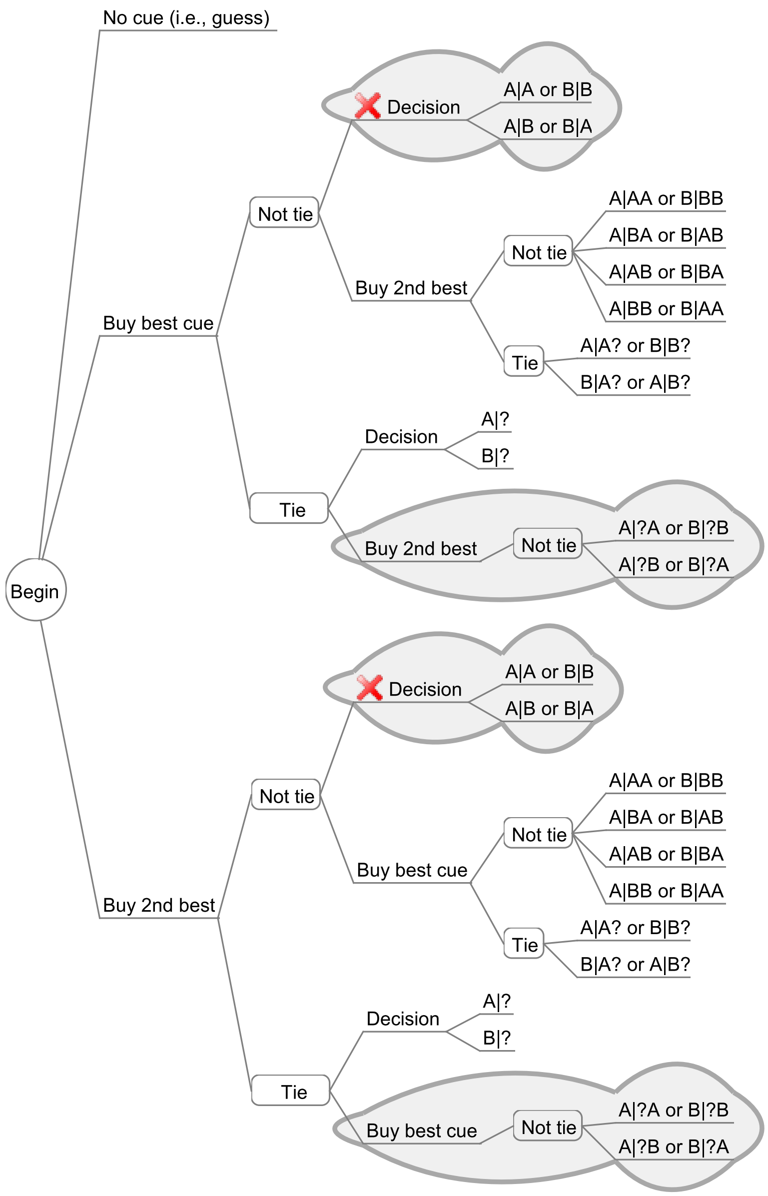

Figure 4.5: Illustration of TTB stop

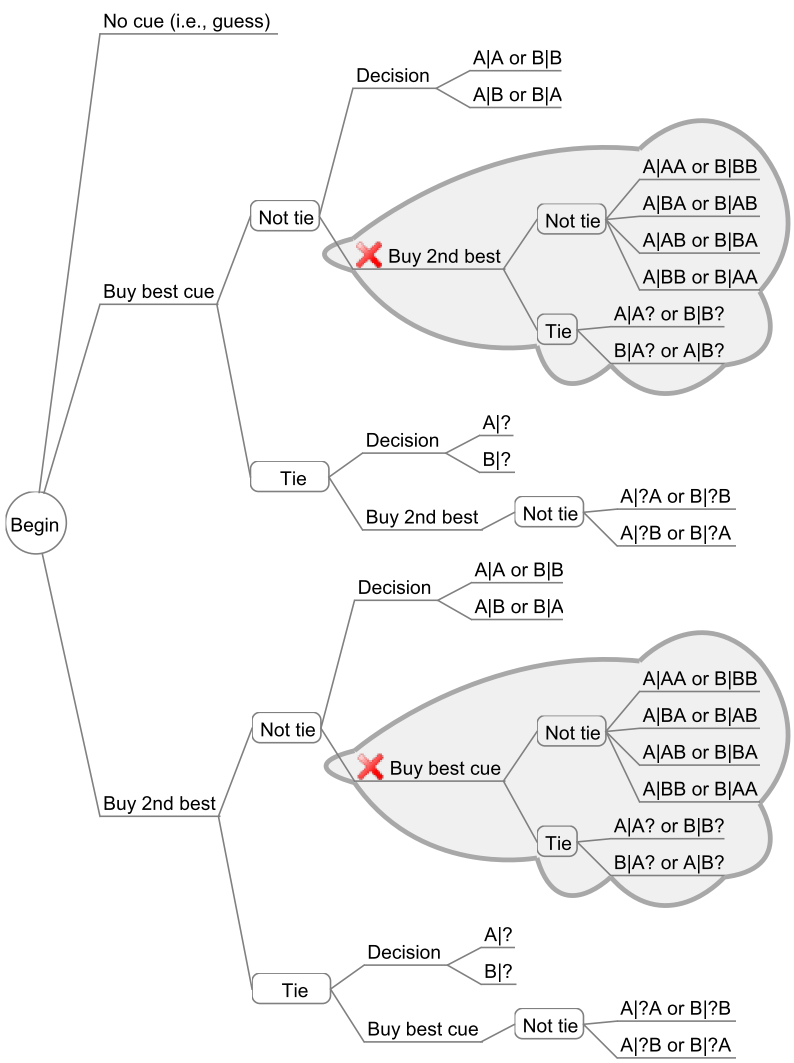

Figure 4.6: Illustration of late stop

	Excluded	Early stop	TTB stop	Late stop	Total counts
Base case	54.6%	5.3%	27.8%	12.3%	2460
Non-compensatory (Trt 1)	54.1%	8.0%	25.6%	12.3%	1560
Non-free information (Trt 2)	56.6%	9.3%	25.1%	9.1%	2340
No-social norm (Trt 3)	54.5%	4.5%	28.0%	13.0%	2400
Overall	55.0%	6.6%	26.7%	11.6%	8760

Table 4.5: Proportion of trials with different stopping rules based on the trials with tied-first cue

4.2.3.3 TTB decision

The TTB decision rule states that a decision should be consistent with the first non-tied cue. For the calculation of the proportion of trials in which the decision rule was followed, trials in which there was no initial direction was excluded. These excluded trials include two cases. The first case is the trials in which no information is purchased at all. The second is the trials in which some pieces of information are purchased but all are tied. That is, the proportion of excluded trials is the same as the sum of 'excluded trials' in Table 4.4 and 'early stop' in Table 4.5. The proportions of trials excluded, those of trials in which the decision rule was violated, and those of trials in which the decision rule was followed are shown in Table 4.6. An illustration of the decision rule is presented in Figure 4.7.

Note that the adherence to the decision rule can be affected by the number of conflicting cues, among the purchased ones, to the first non-tied cue. For example, the Case I is that the first cue purchase favors A, but the second, third, and fourth cues purchased favor B; the Case II is that the first cue purchased favors A and the second, third, fourth cues are tied. Then, it is more likely that the decision rule is not followed in the Case I. If the participants use non-compensatory strategy such as the TTB heuristic, then there will be no conflicting cues; as a result, the decision rule will very likely be followed. However, if the participants use a compensatory strategy and there are conflicting cues, then the decision rule may not be followed. The late stop could be an indication of using a compensatory strategy; therefore, the proportion of the decision rule followed can be different on the condition of

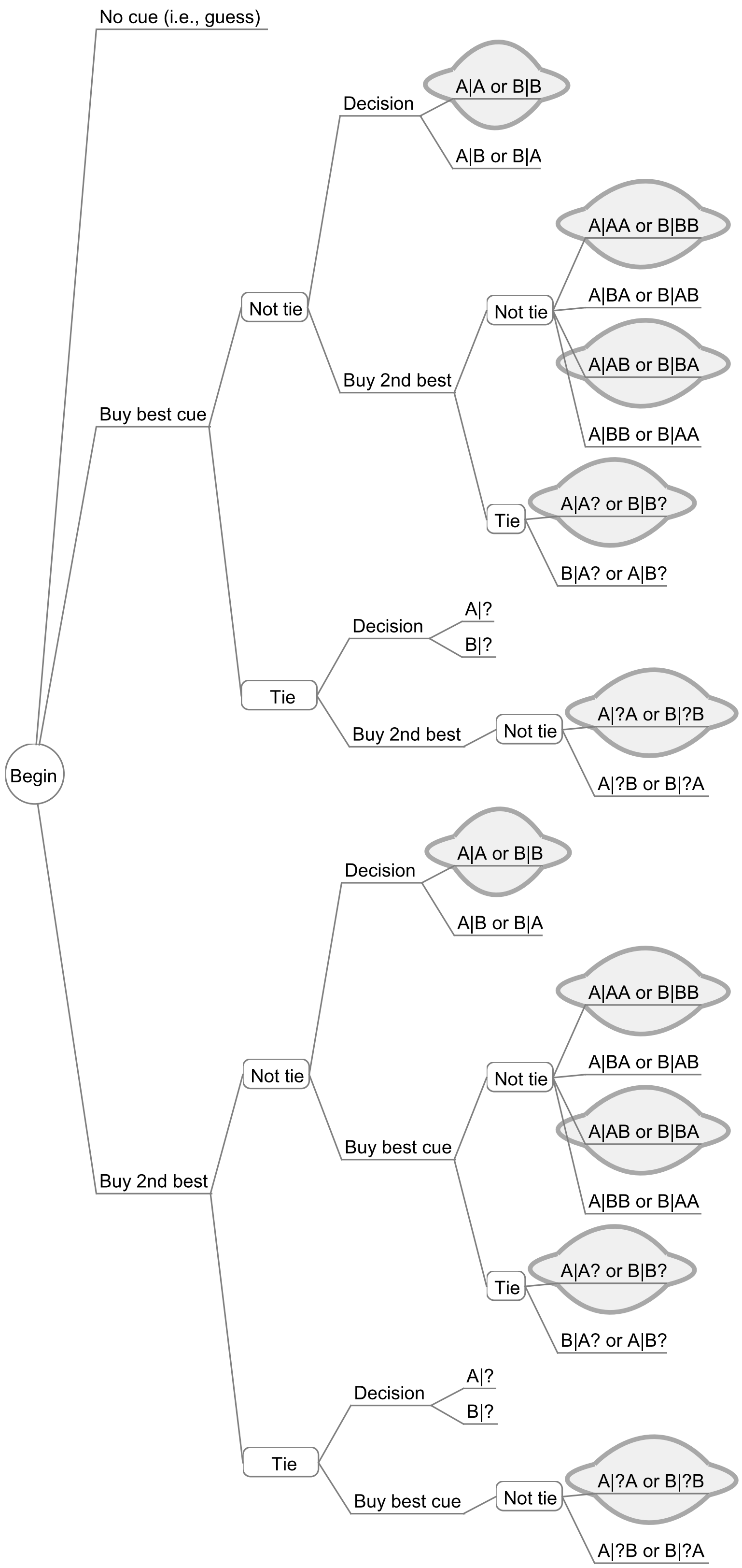

Figure 4.7: Illustration of the decision rule

the stopping rule: TTB stop vs. late stop. Note that the trials with early stop are excluded in the analysis of the decision rule. This conditional nature of the decision rule is analyzed in Section 5.5.

	Excluded trials	Decision rule violated	Decision rule followed	Total counts
Base case	16.7%	8.4%	74.9%	2460
Non-compensatory (Trt 1)	14.4%	11.8%	73.8%	1560
Non-free information (Trt 2)	18.9%	7.1%	74.0%	2340
No-social norm (Trt 3)	12.3%	10.2%	77.5%	2400
Overall	15.7%	9.1%	75.2%	8760

Table 4.6: Proportions of trials with the decision rule

4.2.4 The proportion of a correct choice

The proportion of correct choice is calculated. This variable is used for a manipulation check, that is, whether the proportion of correct answer is above the chance level. The experimental setting of this study is probabilistic. That is, once a participant chooses an alternative, a random number generator will determine the correct alternative based on the calculated probability[5] in each trial. Therefore, even if the participants follow the TTB heuristic, their answer may not be correct. In fact, according to our simulation (1000 times of all 2108 comparisons) reveals that for the compensatory information the mean accuracy of the TTB trial is about 77.8%. For the non-compensatory information the mean accuracy of the TTB trial is about 82.2%.

Note that this variable does not capture whether or not the participant follow the TTB heuristic; rather, it capture whether or not he/she is correct regardless of a decision strategy he or she uses. The former is captured by the proportion of TTB trials discussed in Section 4.2.2.

[5] See appendix B.

4.3 Analysis

4.3.1 Test of the hypotheses

The hypothesized effect of each treatment was tested by comparing the dependent variable (i.e., the proportion of TTB trials) of the base case with that of each treatment case. Since both dependent and independent variables have only two possible values, a 2×2 contingency table, in which the rows are the two levels of the independent variable (e.g., base case vs. treatment 1) and the columns are the two levels of the dependent variable (i.e., TTB vs. non-TTB), can be formed. In this table, to test the effect of a treatment on a dependent variable, we tested whether the true proportion of TTB trials in the base case (π_{base}) was significantly different from that of the treatment group ($\pi_{\text{treatment}}$) by using the z-test of proportions. The test statistic z follows the standard normal distribution and is calculated as follows:

$$z = \frac{p_{\text{base}} - p_{\text{treatment}}}{\sqrt{p(1-p)\left(\frac{1}{N_{\text{base}}} + \frac{1}{N_{\text{treatment}}}\right)}},$$

where $p_{\text{base}}$and $p_{\text{treatment}}$ are observed proportions of TTB trials in contingency table of the base case and that of treatment case, respectively; N_{base} and $N_{\text{treatment}}$ are the sample size of the case and that of treatment case, respectively; p is the proportion of TTB trials when the base and treatment cases are lumped together. The hypotheses presented in this dissertation are directional ones, and the z-test of proportions can do a directional test (i.e., which proportion is bigger). In addition, a 95% confidence interval for the population proportion difference is calculated by:

$$(p_{\text{base}} - p_{\text{treatment}}) \pm 1.96\sqrt{\frac{p_{\text{base}}(1-p_{\text{base}})}{N_{\text{base}}} + \frac{p_{\text{treatment}}(1-p_{\text{treatment}})}{N_{\text{treatment}}}}.$$

Since the only difference between the base case and experiment with treatment 1 is the information structure (i.e., compensatory vs. non-compensatory), the comparison between the proportion of TTB trials in the base case and experiment with treatment 1 is expected to test the effect of information structure on the use of the TTB heuristic; that is, whether the TTB heuristic is used more often in a non-compensatory environment: hypothesis 1. The null hypothesis is:

> The proportion of TTB trials in the environment of non-compensatory information structure is less than or equal to that in the environment of compensatory one (i.e., $\pi_{\text{non-compensatory}} \leq \pi_{\text{compensatory}}$).

The alternative hypothesis is:

> The proportion of TTB trials in the environment of non-compensatory information structure is greater than that in the environment of compensatory one (i.e., $\pi_{\text{non-compensatory}} > \pi_{\text{compensatory}}$).

The only difference between the base case and treatment 2 is the information cost (i.e., free when wrong vs. not free). In the base case (and the experiments of B. Newell and Shank (2003) and of B. Newell et al. (2003), information is free when participants make a wrong choice. Participants earn seven dollars minus one dollar for each cue viewed in each trial if they answer correctly. However, in the case of a wrong answer there is no gain or loss. This kind of environment may make the participants buy more pieces of information after discovering a non-tied cue without an uneasy feeling. The experiment with treatment 2, however, does not have free information even when the participants are wrong. This environment will require a higher level of frugality in decision making compared to that of experiment 1. Therefore, the comparison between the proportions of TTB trials in the base case and experiment with treatment 2 will test the effect of information cost on the use of the TTB heuristic: hypothesis 2. The null hypothesis is:

> The proportion of TTB trials in the environment of high perceived information cost is less than or equal to that in the environment of low perceived information (or low information cost) (i.e., $\pi_{\text{high information cost}} \leq \pi_{\text{low information cost}}$).

The alternative hypothesis is:

> The proportion of TTB trials in the environment of high perceived information cost is greater than that in the environment of high perceived information cost (i.e., $\pi_{\text{high information cost}} > \pi_{\text{low information cost}}$).

The only difference between the base case and experiment with treatment 3 is the existence of a social norm. Unlike the stock prediction task, we assume that the fish task is so novel that there is no established social norm regarding the questions asked in the experiment. The comparison between the proportions of TTB trials in the base case and experiment with treatment 3 is then expected to test whether social rationality affects the choice of heuristics: hypothesis 3. If the TTB heuristic is used more often in the fish task, then I may say that the result of Newell et al. is confounded by the demand characteristic of the experiment. Further, the participants in the original study might have been acting socially rationally. A null hypothesis is:

> The proportion of TTB trials in the environment without a social norm is less than or equal to that in the environment with a social norm opposed to the TTB heuristic (i.e., $\pi_{\text{no social norm}} \leq \pi_{\text{social norm}}$).

An alternative hypothesis is:

> The proportion of TTB trials in the environment without a social norm is greater than that in the environment with a social norm opposed to the TTB heuristic (i.e., $\pi_{\text{no social norm}} > \pi_{\text{social norm}}$).

4.3.2 Effect of the treatments on three rules of the TTB heuristic

A test statistic and null hypothesis

If a two-way contingency table has more than two columns or two rows or both, then the z-test of proportions is not desirable for testing the effect of an independent variable on a dependent variable. This is because it involves multiple comparisons of proportions, which increase the Type I error. In an $I \times J$ contingency table where $I > 2$ or $J > 2$ or both, a chi-squared test of independence is used for testing the association between two variables. The tests of treatment effect on the search and decision rule will be done in 2×2 contingency tables, but that of treatment effect on the stopping rule will be done in 2×4 contingency tables. Therefore, the test of stopping rule requires a chi-squared test statistic.

In this dissertation, likelihood-ratio statistic G^2 is used:

$$G^2 = 2\Sigma n_{ij} \log\left(\frac{n_{ij}}{\hat{\mu}_{ij}}\right),$$

where n_{ij} and $\hat{\mu}_{ij}$are a cell count and estimated expected frequency, respectively, in the i^{th} row and the j^{th} column in a two-way contingency table. When the sample size is large[6], G^2 follows chi-square distribution with *(I-1)(J-1)* degrees of freedom. G^2 and the Pearson chi-squared statistic, χ^2, offer similar values and commonly yield the same conclusion. One advantage of using G^2 over X^2 is that the former offers exact partitionings[7] (Agresti, 1996), which will be explained later in this section.

The null hypothesis of the chi-squared test of independence is that the proportion of one variable (e.g., the proportion of TTB trials) is the same for different values (e.g., compensatory and non-compensatory) of the other variable. That is, the proportion of any particular column value *j* is the same for each row. In the case of rejecting the null hypothesis, this test does not assess which column value(s) are significantly different for different rows. Therefore, the result of the chi-squared test of independence simply suggests the degree of the existence of an association between two variables (Agresti, 1996). When the null hypothesis of the chi-squared test of independence is rejected, analyzing the residuals of each cell is often useful to find out the nature of differences (i.e., which cell violate the null hypothesis of independence).

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[6] $n/IJ > 5$, where n is a total number of samples in a table (Agresti, 1996).

[7] See "Partitioning a chi-squared statistic" on page 71.

Adjusted residuals

When the null hypothesis is true, cell counts n_{ij} should be very close to estimated expected frequencies $\hat{\mu}_{ij}$. Therefore, a large absolute value of the raw difference, $n_{ij} - \hat{\mu}_{ij}$, indicates the lack of fit of the null hypothesis in that cell. However, the raw differences tend to be bigger in absolute value with large estimated expected frequencies. Therefore, instead of the raw difference, an adjusted residual is a useful figure to assess to the nature of a significant result (i.e., rejection of the null hypothesis). The adjusted residual is calculated by:

$$\frac{n_{ij} - \hat{\mu}_{ij}}{\sqrt{\hat{\mu}_{ij}(1-p_{i+})(1-p_{+j})}},$$

where p_{i+} and p_{+j} are marginal proportion of the i^{th} row and that of the j^{th} column, respectively. An absolute value of an adjusted residual greater than 2 or 3 indicates the lack of fit of the null hypothesis (i.e., $n_{ij} = \mu_{ij}$) in that cell (Agresti, 1996). A large positive (negative) value of the adjusted residual suggests that observed cell count is greater (less) than the expected frequency under the null hypothesis of independence.

Partitioning a chi-squared statistic

Once the null hypothesis is rejected, chi-squared test statistics (e.g., G^2 or X^2) having df > 1 can be partitioned so that the components represent certain aspects of the association. A partitioning may reveal that a significant result mainly reflect differences between certain categories or groupings of categories (Agresti, 1996). That is, by partitioning, one may find that the association(s) between certain (groupings of) categories is significant, while those between other (groupings of) categories are not significant. A partitioning of chi-squared statistics is done by first partitioning an original contingency table and then calculating chi-squared test statistics for each of the partitioned subtables. Necessary conditions for determining subtables for which components of chi-squared are independent are (Agresti, 1990):

1. The degrees of freedom for the subtables must sum to the degrees of freedom for the original table.
2. Each cell count in the original table must be a cell count in one and only one subtable.
3. Each marginal total of the original table must be a marginal total for one and only one subtable.

Note that, there would be many different ways of partitioning that conform to the above conditions. The chi-squared test statistics G^2 offers an exact partitioning, which means that the sum of all G^2 values for subtables is equal to G^2 of the original table.

4.3.3 Chi-squared test for ordinal variable

The chi-squared test of independence treats each variable in a contingency table as a nominal variable. Therefore, when one or more variables in a contingency table are ordinal variables, test statistics that acknowledge the ordinality are more appropriate (Agresti, 1996). To examine whether the participant can learn the cue hierarchy, one can examine whether the proportion correct increases by the blocks to trials. That is, a contingency table with blocks (ordinal variable) and the proportion correct (nominal variable) will be built and analyzed.

A test statistic $M^2 = (n-1)r^2$ is used for testing the null hypothesis of independence against the alternative hypothesis of non-zero true correlation, where n is the sample size and r is a sample correlation[8]. When the sample size is large, M^2 follows approximately a chi-squared distribution with df = 1. Therefore, M follows approximately a standard normal distribution and can be used for directional test. The null hypothesis is:

> The correlations between the block and the proportion correct is zero.

The alternative hypothesis is:

> The correlation between the block and the proportion correct is positive.

The critical value for alpha of 0.05 is 1.64 based on a standard normal distribution.

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[8]A formula for calculating r can be found in Agresti (1990, p. 35).

Chapter 5

Results

The analysis of proportion correct for each condition is presented first in section 5.1. Then, result of testing the relevant null hypothesis is presented in sections 5.2, 5.3, and 5.4. Additionally, in each of the three sections (i.e., section 5.2, 5.3, and 5.4), three building blocks of the take-the-best (TTB) heuristic (i.e., the search, stopping, and decision rule) are analyzed in a exploratory manner.An exploratory analysis does not involve test of formally written hypotheses. Rather, it looks for meaningful patterns from the data, which can provide more insight regarding the relationship between each of the three rules and the factors of interest. The exploratary analysis is done through two methods: the confidence interval of true proportion difference and the chi-square test of independence. The former is used for the analysis of the search and decision rule, and the latter is used for the analysis of the stopping rule. For the search and decision rule, based on the confidence interval, we examine whether or not the difference is positive, negative, or inconclusive. For the stopping rule, we use the technique of partitioning contingency table as well as analysis of adjusted residual to find out whether a certain condition favors a certain stopping rule.

5.1 Proportion correct

Proportions of correct responses across 180 trials in each experiment are shown in Table 5.1. They are around 0.70, which is about the same as that of the experiment 1 in B. Newell and Shank Newell and Shanks (2003). All of mean proportions correct are statistically different from 0.5, which is a chance level. A chi-square independence test between experiment and proportion correct shows that they are independent (p-value: 0.616). That is, proportion correct is statistically the same across the experiments.

	Proportion correct	p-value (χ^2 test)[a]
Base case	.6985	<.0001
Non-compensatory (Treatment 1)	.6951	<.0001
Non-free information (Treatment 2)	.6950	<.0001
No-social norm (Treatment 3)	.6885	<.0001

[a] H_0: Proportion correct = Proportion wrong = .5

Table 5.1: Proportion correct across 180 trials in each experiment

In each experiment, the linear relationship between block of 60 trials (block: 1, 2, 3) as an explanatory variable and proportion correct as a response variable is tested, and the test statistic M is greater than the critical value 1.64. That is, as the participants gained more experience in the experiments, they had higher mean proportion correct. According to the figures in Table 5.2, proportion correct seems to increase by a greater margin after the first hint of cue hierarchy (i.e., from block 1 to block 2) than after the second hint. The proportions correct by the block and a value of the test statistic M are shown in Table 5.2.

	Block 1	Block 2	Block3	M
Base case	.6748	.7138	.7069	2.45
Non-compensatory (Treatment 1)	.6365	.7179	.7308	5.72
Non-free information (Treatment 2)	.6667	.7167	.7017	2.60
No-social norm (Treatment 3)	.6508	.6954	.7192	5.11

Table 5.2: Proportion correct per block in each treatment

5.2 Hypothesis 1 – information structure

> **Hypothesis 1:** The proportion of TTB trials in non-compensatory structure is greater than that in compensatory structure.

This hypothesis is about the effect of information structure (i.e., compensatory vs. non-compensatory) on the use of the TTB heuristic. The proportion of TTB trials in the base case is 0.319 and that in the non-compensatory case is 0.315 (Table 4.3). The value of test statistic z is 0.29, and the p-value is 0.6139. That is, the proportions of TTB trials are not significantly different by the information structure. Therefore, hypothesis 1 is not supported.

5.2.1 Exploratory analysis of TTB's three rules

Search rule

As shown in Table 5.3, the proportion of the trials with the search rule followed in the compensatory case is .6021 and that in the non-compensatory case is .4641. A 95% confidence interval for the true proportion difference $\pi_{\text{search:compensatory}} - \pi_{\text{search:non-compensatory}}$ is (0.105, 0.171). Since the confidence interval contains only positive values, we conclude that the proportion of the trials with the search rule followed is greater in the compensatory case than in the non-compensatory case. That is, the compensatory information structure promotes the use of the search rule better than the non-compensatory information structure.

Information structure	Search rule followed? No	Search rule followed? Yes	Total
Compensatory (Base)	867 39.8%	1312 60.2%	2179
Non-compensatory (Trt1)	783 53.6%	678 46.4%	1461

Table 5.3: Frequencies and row percentages of trials of ordered-search for information structures

Stopping rule

A chi-squared test statistic G^2 of Table 5.4 is 12.7251 with df = 2, and the p-value is 0.002. Therefore, the null hypothesis of independence between information structure and the choice of different stopping rules is rejected. That is, the information structure affects the choice of different stopping rules.

According to the adjusted residuals in Table 5.4, a cell count of the early stop in the non-compensatory environment and that of the TTB stop in the compensatory environment are greater than the cell counts predicted by the null hypothesis of independence.

Information structure	Stopping rules			Total
	Early	TTB	Late	
Compensatory (Base)	130 11.63% (-3.52)	685 61.27% (2.36)	303 27.10% (0.13)	1118
Non-compensatory (Trt1)	125 17.46% (3.52)	399 55.73% (-2.36)	192 26.82% (-0.13)	716

Table 5.4: Frequency, percent and adjusted residuals (in parentheses) for testing independence between stopping rule and information structure

Since the degree of freedom of G^2 of the original table is 2, this table can be partitioned into two subtables. The first subtable compares the compensatory and non-compensatory information structures for the (early stop, TTB stop) classification. The test statistic G^2 = 12.7069 with df = 1, and the p-value is 0.000. That is, the proportions of the early stop and of the TTB stop are significantly different for compensatory and non-compensatory information structure. The second subtable compares the information structure for the (early stop or TTB stop, late stop) classification. The test statistic G^2 = 0.0182 with df = 1, and the p-value is 0.893, which implies that the proportions of the late stop and of the others are not significantly different for the different values of information structure. Therefore, the original chi-squared statistic mainly reflects differences between the compensatory and non-compensatory information structures in the choice of the early stop and TTB stop. Note that the sum of G^2 of two subtables is the same as G^2 of the original table.

In sum, the TTB stop is the most favored (more than 50%) stopping rule in both the compensatory and non-compensatory environments. The compensatory environment favors the TTB stop more than the non-compensatory environment does. The non-compensatory environment favors the early stop more than the compensatory environment does. Note that in non-compensatory environment the validity of the second and the third most valid cue are 0.83 and 0.8, respectively. Therefore, it is unlikely that in non-compensatory environment the other cues are so much weaker than the first that the participants gave up and guess if the "good" cue is tied. The proportions of the late stop are statistically the same for the compensatory and the non-compensatory environments.

Decision rule

As shown in Table 5.5, the proportion of the trials with the decision rule followed is 0.8995 in the compensatory case and is 0.8623 in the non-compensatory case. A 95% confidence interval for the true proportion difference $\pi_{\text{decision:compensatory}} - \pi_{\text{decision:non-compensatory}}$ is (0.015, 0.060). Since the confidence interval contains only positive values, we conclude that the proportion of the trials with the decision rule followed is greater in the compensatory case than in the non-compensatory case. That is, the compensatory information structure promotes the decision rule better than the non-compensatory information structure does.

Information structure	Decision rule followed? No	Decision rule followed? Yes	Total
Compensatory (Base)	206 10.1%	1843 89.9%	2049
Non-compensatory (Trt1)	184 13.8%	1152 86.2%	1336

Table 5.5: Frequencies and row percentages of trials with decision rule followed for information structures

5.3 Hypothesis 2 – information cost

> **Hypothesis 2:** The proportion of TTB trials in a high perceived cost condition is greater than that in a low perceived cost condition.

This hypothesis is about the effect of information cost (i.e., low: free information when wrong vs. high: non-free information) on the use of the TTB heuristic. The proportion of TTB trials in the base case is 0.319 and that in the non-free information case is 0.300

(Table 4.3). The value of test statistic z is 1.46, and the p-value is 0.9283. That is, the proportions of TTB trials are not significantly different by the different information cost structure. Therefore, hypothesis 2 is not supported.

5.3.1 Exploratory analysis of TTB's three rules

Search rule

As shown in Table 5.6, the proportion of the trials with the search rule followed in the low information case is 0.6021 and that in the high information cost case is 0.5705. A 95% confidence interval for the true proportion difference $\pi_{\text{search:low infor. cost}} - \pi_{\text{search:high infor. cost}}$ is (0.002, 0.061). Since the confidence interval contains only positive values, we conclude that the proportion of the trials with the search rule followed is greater in the low information cost case than in the high information cost case. That is, the low information cost promotes the use of the search rule better than the high information cost.

Information cost	Search rule followed?		Total
	No	Yes	
Low information cost (Base)	867 39.8%	1312 60.2%	2179
High information cost (Trt2)	908 43.0%	1206 57.0%	2114

Table 5.6: Frequencies and row percentages of trials with search rule followed for information costs

Stopping rule

A chi-squared test statistic G^2 of Table 5.7 is 40.8921 with df = 2, and the p-value is less than 0.0001. Therefore, the null hypothesis of independence between information cost and the choice of different stopping rules is rejected. That is, the information cost affects the choice of different stopping rules.

According to the adjusted residuals in Table 5.7, a cell count of the early stop in the environment of high information cost and that of the late stop in the environment of low information cost are greater than the cell counts predicted by the null hypothesis of independence.

Information cost	Stopping rules: Early	TTB	Late	Total
Low information cost (Base)	130 11.63% (-3.52)	685 61.27% (2.36)	303 27.10% (0.13)	1118
High information cost (Trt2)	217 21.36% (60.8	587 57.78% (-1.64)	212 20.87% (-3.36)	1016

Table 5.7: Frequency, percent and adjusted residuals (in parentheses) for testing independence between stopping rule and information structure

Next, the original table is partitioned into two subtables. Since the cells of the early and late stops lack a fit of the null hypothesis of independence according to the analysis of adjusted residuals, we suspect the proportions of these two stops are greatly different for low and high information cost. Therefore, we form the first subtable by using the (early stop, late stop) classification. The test statistic G^2 = 38.1929 with df = 1, and the p-value is 0.000. That is, as expected, the proportions of early stop and of late stop are significantly different for low and high information cost. The second subtable compares the information cost for (early stop or late stop, TTB stop) classification. The test statistic G^2 = 2.6992 with df = 1, and the p-value is 0.100, which implies that the proportions of the TTB stop and of the others are not significantly different for the different values of information cost. Therefore, the original chi-squared statistic mainly reflects differences between the low information cost and high information cost in the choice of the early stop and late stop.

In sum, the TTB stop is the most favored (more than 50%) stopping rule in environments of both low and high information cost, and the proportions of the TTB stop are statistically the same for the low and high information cost. The environment of the low information cost favors the late stop more than that of the high information cost does. The environment of the high information cost favors the early stop more than that of the low information cost does.

Decision rule

A 95% confidence interval for the true difference between the proportion of trials with the decision rule followed in the low information case and that in the high information case is (-0.031, 0.005). Since the confidence interval contains zero, we conclude that the proportions of trials with the decision rule followed are not different for the low information cost case and the high information cost case. That is, information cost structure does not affect the use of the TTB decision rule.

5.4 Hypothesis 3 – social rationality

> **Hypothesis 3:** The proportion of TTB decision is greater when it not opposed by social rationality than when it is opposed by social rationality.

This hypothesis is about the effect of social rationality on the use of the TTB heuristic. The proportion of TTB trials in the base case is 0.319 and that in the non social norm case (i.e., fish picking task) is 0.368 (Table 4.3). The value of test statistic z is -3.61, and the p-value is 0.0002. A 95% confidence interval for the true proportion difference $\pi_{\text{social norm}} - \pi_{\text{no social norm}}$is (-0.076, -0.023), which contains only negative values. Therefore, we conclude that the proportion of TTB trials when there is no social norm is significantly greater than that of TTB trials when there is a social norm that opposes to the TTB heuristic; hypothesis 3 is supported.

5.4.1 Exploratory analysis of TTB's three rules

Search rule

As shown in Table 5.8, the proportion of the trials with the search rule followed in the environment with a social norm is .6021 and that in the environment without a social norm is .5470. A 95% confidence interval for the true proportion difference $\pi_{\text{search:social norm}} -$

$\pi_{\text{search:no social norm}}$is (0.026, 0.084). Since the confidence interval contains only positive values, we conclude that the proportion of the trials with the search rule followed is greater in the environment with a social norm than in the environment without a social norm. That is, the environment with a social norm promotes the use of the search rule better than that without a social norm.

Social rationality	Search rule followed? No	Yes	Total
Social norm against TTB (Base)	867 39.8%	1312 60.2%	2179
No-social norm (Trt3)	91003 45.3%	1211 54.7%	2214

Table 5.8: Frequencies and row percentages of trials with search rule followed for social norm cases

Stopping rule

A chi-squared test statistic G^2 of Table 5.9 is 1.77 with df = 2, and the p-value is 0.4135. Therefore, the null hypothesis of independence between the social rationality and the choice of different stopping rules is accepted. That is, the social rationality and the choice of different stopping rules are independent. The TTB stop is the most favored (more than 50%) stopping rule in environments of both conditions of the social rationality.

Social rationality	Stopping rules: Early	TTB	Late	Total
Social norm against TTB (Base)	130 11.63%	685 61.27%	303 27.10%	1118
No-social norm (Trt3)	109 9.99%	671 61.50%	311 28.51%	1091

Table 5.9: Frequency and percent for testing independence between stopping rule and information cost

Decision rule

A 95% confidence interval for the true difference between the proportion of trials with the decision rule followed in the environment with a social norm and that in the environment without social norm is (-0.004, 0.034). Since the confidence interval contains zero, we conclude that the proportions of trials with the decision rule followed are not different for the environment with a social norm and the environment without a social norm. That is, a social norm does not affect the use of the TTB decision rule.

5.5 Classification of trials

All the trials in each treatment case are first classified by the search rule: ordered search, non-ordered search, and excluded. Then, within each classification of the search rule, the trials are classified by whether the first cue bought is tied: tied and non-tied. Next, within each group of trials classified in the prior step, the trails are classified by the stopping rule: early, TTB, and late. Finally, within each group of trials classified in the prior step, trials are classified by the decision rule: followed and not followed.

For example, in the base case, the search rule was followed in 1312 (53%) trials; the search rule was not followed in 867 (35%) trials; no information was purchased at all in 281 (11%) trials. Out of the trials in which the search rule was followed (i.e., 1312 trials), the first cue bought was tied in 614 (47%) trials, and it was not tied in 698 (53%) trials. Out of the trials in which the search rule was followed and the first cue bought was not tied (698 trials), the TTB stop was used in 378 (54%) trials; the late stop was used in 320 (46%) trials. Lastly, out of the trials in which the search rule was followed, the first cue bought is not tied and the TTB stop was used (i.e., 378 trials), the decision rule was followed in 377 trials (99.7%). This classification scheme with the number and percentage of trials in each group is shown in Figure 5.1 and Figure 5.2, respectively.

Based on Figure 5.1 and Figure 5.2, the following exploratory findings regarding the relationship between the search rule and the stopping rule can be derived:

1. In general, it seems that the TTB stop is more likely to be used, if the search rule is followed.
2. It seems that the late stop is likely to be used, if the search rule is violated.

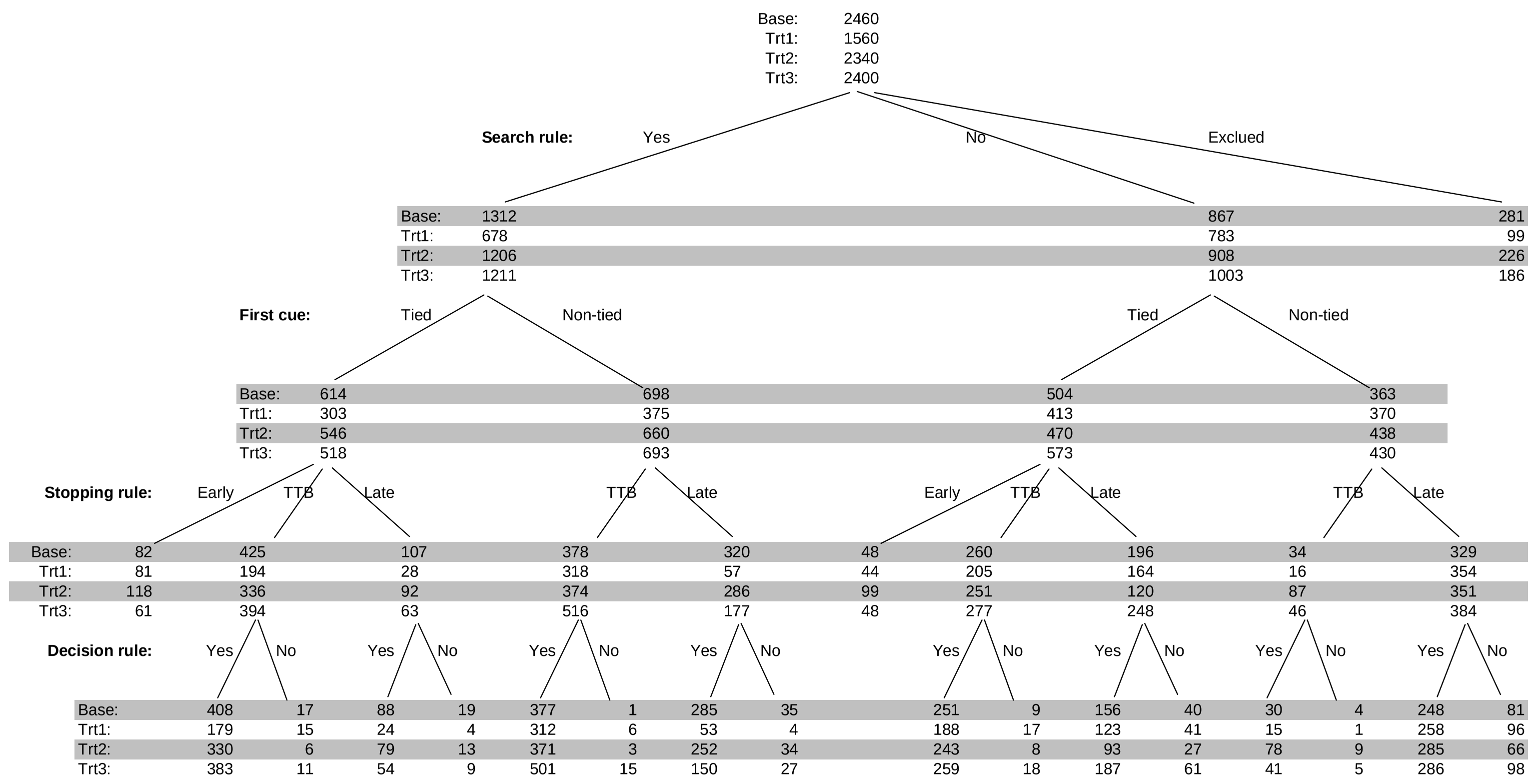


Figure 5.1: Classification of the trials

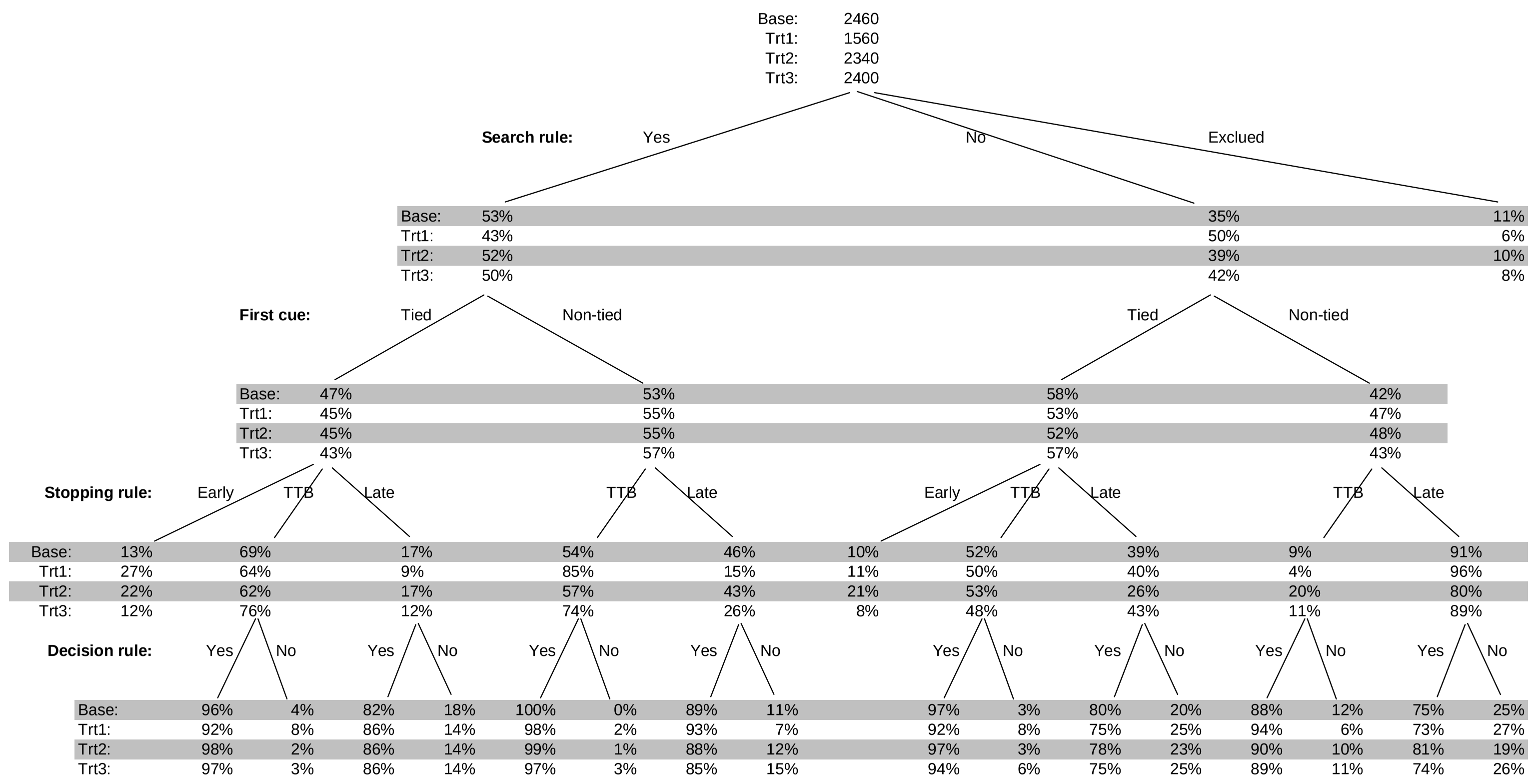


Figure 5.2: Classification of trials with percentages

3. It seems that the late stop is likely to be used, if the first cue bought is not tied.
4. It seems that the late stop is very likely to be used, if the search rule is violated and the first cue bought is not tied.

An example of the relationship 1 is: the percentages of the trials, in which the TTB stop is used given the search rule is followed and the first cue bought is tied, are 69%, 64%, 62% and 76% for the base, treatment 1, treatment 2, and treatment 3, respectively. The percentages of trials, in which the TTB stop is used given the search rule is not followed and the first cue bought is tied, are 52%, 50%, 53% and 48% for the base, treatment 1, treatment 2, and treatment 3, respectively.

Another interpretation of these patterns is that if one is planning on late stop, search order is less important than if one is planning on the TTB stop or on early stop. That is, if the TTB stop is used, then the search will more likely be followed.

In addition to the relationship listed above, the following exploratory finding regarding the relationship between the stopping rule and the decision rule can be derived:

- It seems that the decision rule is followed better, if the TTB stop is used.

For example, the percentages of trials, in which the decision rule is followed given the search rule is followed, the first cue bought is tied and the TTB stop is used, are 96%, 92%, 98%, and 97% for the base, treatment 1, treatment 2, and treatment 3, respectively. The percentages of trials in which the decision rule is followed given the search rule is followed, the first cue bought is tied and the late stop is used are 82%, 86%, 86%, and 86% for the base, treatment 1, treatment 2, and treatment 3, respectively.

5.6 Summary

Only treatment in this dissertation that affects the use of the TTB heuristic is social rationality; neither information structure nor information cost affects the use of the TTB heuristic.

When three building blocks of the TTB heuristic are examined under each treatment condition, the following relationships are found:

1. Information structure: compensatory vs. non-compensatory information

   (a) The compensatory information structure promotes the search rule, the TTB stopping rule and the decision rule better.
   (b) The non-compensatory information promotes the early stop better.

2. Information cost: low perceived cost vs. high perceived cost

   (a) The low perceived cost promotes the search rule and the late stop better.
   (b) The high perceived cost promotes the early stop better.

3. Social rationality: stock vs. fish

   (a) The stock experiment promotes the search rule better.
   (b) The fish experiment promotes the TTB heuristic better.

The analysis results are summarized in Table 5.10.

Treatment	TTB heuristic	Search rule	Early stop	TTB stop	Late stop	Decision rule
Information structure	-	Comp	Non-comp	Comp	-	Comp
Information cost	-	Low	High	-	Low	-
Social rationality	Fish	Stock	-	-	-	-

Table 5.10: Summary of the analysis

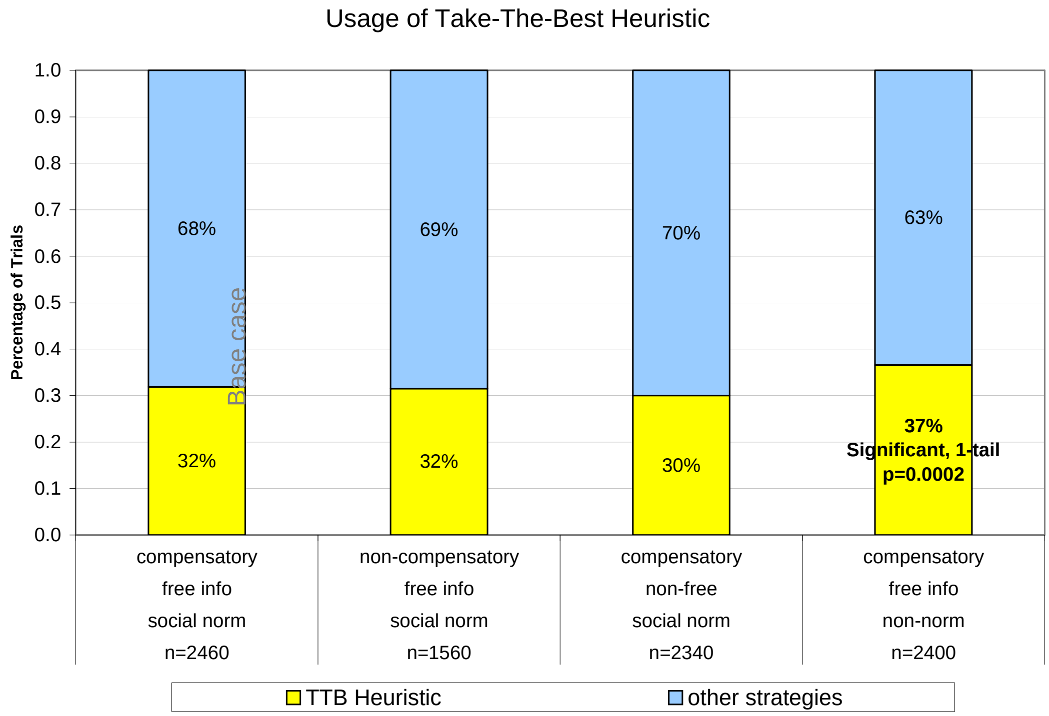


Figure 5.3: Proprotions of TTB trials by the conditions

Additionally, analysis results are illustrated using bar charts, in which the proportions of the dependent variables are shown. In the following figures, significance test results (i.e., p-values) of each treatment are calculated through the comparisons between the base case and each treatment case.

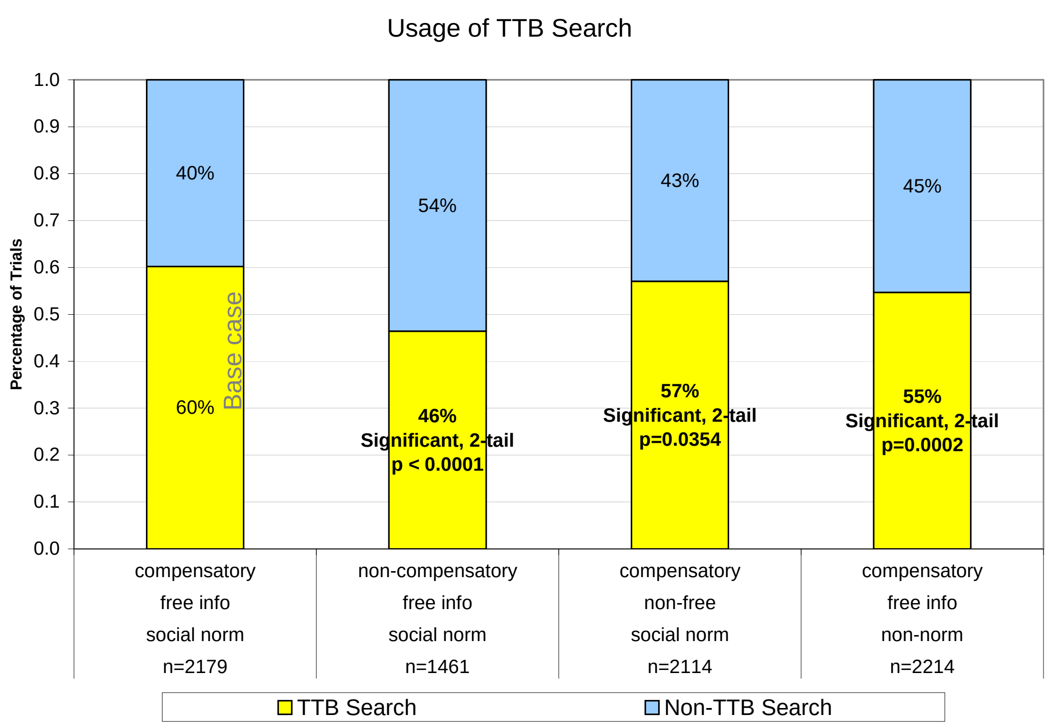
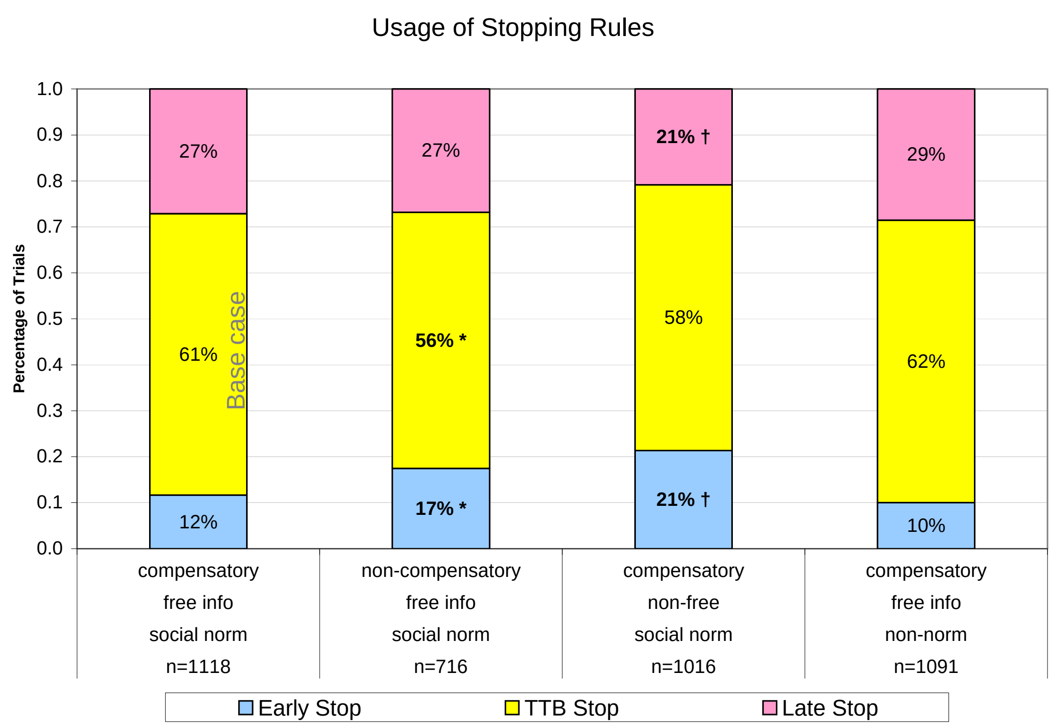


Figure 5.4: Proprotions of TTB search by the conditions



*: $G^2 = 12.7069$, p-value < 0.0001

†: $G^2 = 38.1929$, p-value < 0.0001

Figure 5.5: Proprotions of the stopping rule by the conditions

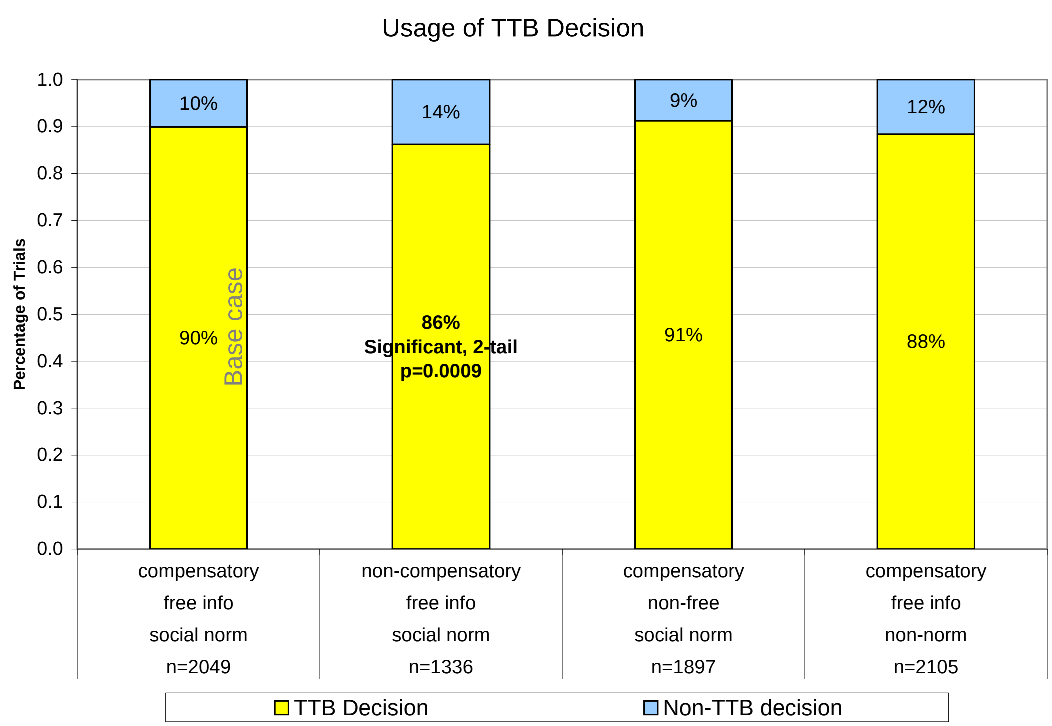


Figure 5.6: Proprotions of the TTB decision by the conditions

Chapter 6

Discussion

In this dissertation, the question of how heuristics are selected from the adaptive toolbox is investigated; specifically, "When is the take-the-best (TTB) heuristic more likely to be used?" This study was started by finding out a few flaws of the past experiments testing the effects of environmental factors on the use of the TTB heuristic. Three research questions are formed based on these flaws, and the experiments were carried out to test whether or not such flaws affected the result of past experiments, specifically the one by B. Newell et al. (2003).

The TTB heuristic is composed of four sequential steps: recognition heuristic, search rule, stopping rule, and decision rule.[1] The exploratory findings in section 5.5 suggest that three rules of the TTB heuristics are not independent of each other. The stopping rule seems to be correlated with the search rule, and the decision rule also seems to be correlated with the stopping rule. Therefore, when discussing the treatment effect on the individual rules of the TTB heuristic, we will consider such interrelated nature of these rules.

6.1 Information structure

First, information structure is manipulated: compensatory vs. non-compensatory. Bröder (2000) tested the effect of information structure and found that the difference between the TTB users in non-compensatory and those in compensatory environment was not signifi-

[1] See section 2.3.1.

cant. We argued in Section 3.1 that the previous findings were weak.

The test result of hypothesis 1 tells us that information structure does not affect the use of the TTB heuristics. This result is in line with the finding of Bröder (2000), and it may indicate that people are insensitive to information structure; especially, when there are many cues available. This may be caused by the inability to appreciate the nature of non-compensatory information; that is, in the experiment with non-compensatory information, the probability that the stock favored by the first non-tied most valid cue is more profitable is always greater than 0.5 no matter which alternative is favored by the remaining cues. Without knowing that, the participants may have wanted to buy more information to increase the confidence in their choices.

When we scrutinized the three rules of the TTB heuristic, the proportions of trials in which search, stopping or decision rule was followed are significantly different for compensatory and non-compensatory information. The compensatory information favors the ordered search. For the stopping rule, the non-compensatory information favors the early stop; the compensatory information favors the TTB stop. Lastly, the compensatory information promotes the decision rule better.

The difference in the use of the search rule for different information structures was not expected as the hint of cue hierarchy was given in both conditions. When the search rule is followed, there is an interesting pattern of the stopping rule. First, when the first cue bought is not tied, the proportion of the trials with the TTB stop is significantly higher with non-compensatory information (85%) than with compensatory information (54%). The proportion of the trials with the late stop is significantly lower with non-compensatory information (15%) than with compensatory information (46%). A chi-squared statistic G^2 for this subtable is 108.78 with df = 1, and its p-value = 0.00.

When the search rule is followed and the first cue bought is tied, the proportion of late stop is lower with non-compensatory information (9%) than with compensatory information (17%). In addition, the proportion of early stop is higher with non-compensatory information (27%) than with compensatory information (13%). The proportion of the TTB stop is about the same in both conditions.

These results suggest that once the participants follow the search rule, they bought less information in the environment with non-compensatory information than in the environment with compensatory information. Participants in the environment with non-compensatory information may have found that additional information was not needed once the first cue bought was not tied. This may explain why the proportion of early stop is higher with non-compensatory information than with compensatory information. For the participants who followed the search rule, when the first cue bought is tied, they may have felt that only the most valid cue matters; therefore, they may have guessed (i.e., early stop).

When the search rule is not followed and the first cue bought is tied, there is no significant difference between non-compensatory and compensatory information in the use of different stopping rule. When the first cue bought is not tied, the proportion of late stop is slightly higher with non-compensatory information (96% vs. 91%).

All in all, even though the hypothesis 1 is not supported, the participants who followed the search rule can be said to be adaptive to the environment.

6.2 Information cost

Even though the investment in information acquisition is arguably the most important factor (Bröder, 2000), the effect of information cost difference on the strategy selection is not clear. The analysis of Bröder's (2000) experiment 3 indicated a significant effect of cost difference, but the significant level used in the analysis was too high ($\alpha = 0.24$) to draw a concrete conclusion.[2] B. Newell and Shank (2003) found that the TTB stopping rule was followed more often under the high relative cost condition, but the difference was not significant at $\alpha = 0.05$. The current study provides the experiments from which a more

[2] See page 32.

concrete conclusion about the effect of information cost difference on adaptivity of strategy selection can be drawn.

The test result of hypothesis 2 tells us that the differences in information cost used in the experiment do not affect the use of the TTB heuristics. Even though the past studies (e.g., Bröder's (2000) experiment 3) concluded that the information cost was a significant factor affecting the use of the TTB heuristic, their results said otherwise if the conventional significance level (i.e., $\alpha = 0.05$) had been used. Therefore, with α level of 0.05, the test result of the hypothesis 2 is in line with the results of the past findings of Bröder's (2000). Based on this one may argue that the cost difference was not great enough to induce the significant results. However, the examination of three rules individually reveals that there are differences in participants' behavior.

The search rule was followed better in the low cost condition. Overall, the high cost condition favors early stop, and the low cost condition favors late stop. Such a pattern of the stopping rule indicates that participants were sensitive to the cost of information.

When the search rule is followed and the first cue bought is not tied, the proportion of the TTB stop is slightly higher with high information cost (57%) than with low information cost (54%). The proportion of the late stop is slightly lower with high information cost (43%) than with compensatory information (46%). This relationship is not statistically significant ($G^2 = 0.87$, df = 1, p-value = 0.35).

When the search rule is followed and the first cue bought is tied, the proportion of the TTB stop is slightly lower with high information cost (62%) than with low information cost (69%). In addition, the proportion of early stop is higher with high information cost (22%) than with low information cost (13%). The proportion of the late stop is about the same in both conditions (17% vs. 17%). This relationship is significant ($G^2 = 14.09$, df=2, p-value=0.00). Based on the partitioning of G^2, the significance result reflects mostly the difference in early stop. Therefore, when the search rule is followed, participants favor the early stop, if it is available; if the early stop is not available, there is no significant difference in the stopping rule.

When the search rule is not followed, the early stop is favored by high information cost condition (21% vs. 10%), and the late stop is favored by low information cost condition (39% vs. 26%). The proportion of the TTB stop is about the same (52% vs. 53%). If the early stop is not available (i.e., the first cue bought is not tied), then the high information cost condition favors the TTB stop (20% vs. 9%).

In sum, even though the hypothesis 2 is not supported, the participants in the high cost condition acted frugally by not buying much information to a degree to favor the early stop over the TTB stop.

6.3 Social rationality

This study is the first one to test the effect of social rationality on the use of the TTB heuristic. Hypothesis 3 questions the appropriateness of using the stock prediction task in the empirical test of the TTB heuristics, which is a dominant paradigm in the empirical study of TTB.

The test result of hypothesis 3 tells us that social rationality is a significant factor in the use of the TTB heuristic. The stock prediction task (i.e., the base case) has a social norm that is opposed to the TTB stopping rule, that is, to buy multiple cues before making a decision. On the contrary, the fish picking task does not have a social norm regarding the stopping rule. Therefore, if participants are affected by the social norm, there will be more stopping rule violations in the stock experiment. In addition, if participants are planning on late stop (i.e., follow the social norm), they do not have to adhere strictly to the search rule. For an extreme case, if participants plan to buy all six cues, then the search rule does not matter to them. Also, the use of multiple cues can impact the adherence to the decision rule, especially in the compensatory environment as in the base and the fish experiment.[3]

[3] See Section 4.2.3.3 for more detailed discussion.

The analysis of three individual rules reveals that the search rule was followed better in the stock experiment than in the fish experiment. The use of the stopping and decision rules are not significantly different for stock and fish experiments, which is against my reasoning above. However, once we classified the trials further based on the search rule and the first cue bought, interesting patterns emerge.

When the search rule is followed and the first cue bought is not tied, the proportion of the trials with the TTB stop is significantly higher in fish experiment (74%) than in stock experiment (54%). Also the proportion of the trials with the late stop is lower in fish experiment (26%) than in stock experiment (46%). This relationship is statistically significant (G^2 = 63.10, df = 1, p-value = 0.00).

When the search rule is followed and the first cue bought is tied, the proportion of the TTB stop is higher in the fish experiment (76%) than in the stock experiment (69%). In addition, the proportion of late stop is lower in the fish experiment (12%) than in the stock experiment (17%). The proportion of the early stop is about the same (13% vs. 12%) in both conditions. This relationship is also significant ($G^2 = 7.64$, df = 1, p-value = 0.022).

When the search rule is not followed, regardless whether or not the first cue bought is tied, the proportion of different stopping rules are not significantly different for the fish and stock experiments (see Figure 5.2).

These results of exploratory analysis suggest that the fish experiment favors the TTB stop when the search rule is followed. Such a pattern was shown more strongly when the early stop was not available (i.e., the first cue purchased is not tied). In sum, the effect of a social norm in the stock experiment seems to be significant when the search rule was followed.

The TTB heuristic is defined by a sequential use of multiple rules (i.e., search, stopping and decision rule). If these rules are indeed interrelated as discussed in here and Section 4.2.3.3 as well as in Section 5.5, then the significant result of hypothesis 3 tells us that the effect of the social norm on the use of the stopping rule may be strong. A social norm affects the stopping rule, which in turn affects the use of the search rule and of the decision rule. The search rule and the decision rule will be more likely to be followed, which results in the higher use of the TTB heuristic, when the TTB stop is planned than when the late stop is planned. Therefore, based on these exploratory analysis result, it can be said that the effect of the social norm on the use of the TTB heuristic is significant, and the participants in the base case as well as in B. Newell et al.'s (2003) experiment 1 were adaptive to the environment, more specifically social environment.

6.4 Summary of Contributions

Theoretical contributions

There are three contributions to the study of the TTB heuristic. First, this study suggests and tests a potential flaw of past experimental designs. Based on mathematical analyses, non-compensatory information is found to be one of the environments that promote the use of the TTB heuristic well; the TTB heuristic can be outperformed by other compensatory strategies in an environment with the compensatory information. Most of past experiments were claimed by the creators to be designed to promote strongly the use of the TTB heuristic. In many of them, however, the compensatory information was used, which could have affected the result of experiments. Even though the findings of this study suggest that information structure does not affect the use of the TTB heuristic, those who followed the search rule in the compensatory environment used late stop more than those in non-compensatory environment did. Therefore, in this study, past experiments are not found to be flawed. However, it should be noted that the effect of information structure is not zero, and thus it should be considered carefully in the design of future experiments.

Second, this study solves the conflict about the effect of information cost found in the past experiments. In Bröder's (2000) experiment 3, the effect of information cost found to be significant, but B. Newell and Shank (2003) found that the effect of information cost was not significant in their experiment 1. Further, each of these results is not concrete enough to draw clear conclusions. In Bröder's study, due to small sample size, a significance level of the test used was 0.24. Therefore, the level of type I error of the test was too high, which meant that the probability that the test falsely rejected the null hypothesis when the null hypothesis was true, was too high. In the experiment of B. Newell and Shank, the search rule was violated too much to draw a conclusion about the effect of information cost on the use of the TTB heuristic. The findings of this study suggest that the information cost does not affect the use of the TTB heuristic. Therefore, this study provides another ground to believe the information cost does not affect much the use of the TTB heuristic. At the same time, this study suggests that the high information cost condition favors the early stop, which is even more frugal than the TTB stop.

Third, this study provides novel insight on the effect of social rationality, which has not been empirically studied in the theory of fast and frugal heuristics. Gigerenzer et al. (1999) reported the importance of social rationality on the selection of heuristics in the adaptive toolbox. However, there has been no empirical test on the effect of social rationality on the use of the TTB heuristic, and the current study is the first one to test such an effect. The results of this study suggest that the environment with no social norm against the stopping rule favors *strongly* the TTB heuristic as well as the stopping rule. Another set of novel findings are from the exploratory analysis of three individual rules of the TTB heuristic. Findings suggest that search, stopping, decision rules are inter-related. Those who follow the search rule are more likely to follow the stopping rule. Those who follow the stopping rule and the search rule are more likely to follow the decision rule.

These findings have an important bearing on the empirical study of the TTB heuristic. The dominant paradigm in the test of the TTB heuristic uses a stock as a stimulus, but based on this result, future experimental designs should be careful in using the stock as a stimulus as doing so may confound the analysis results.

Managerial contribution

This study is about what affects the choice of decision strategies, rather than what decision strategy should be used under a certain circumstance. In organizations, there are situations when deep thinking is more appropriate and others when fast and frugal thinking is more appropriate. Based on the result of this study, a social factor (e.g., a social norm) is more important than environmental factors (e.g., information structure and information cost) in influencing which decision strategy is used. If management wants their employees to think in a fast and frugal way, then it is advised to establish a social norm that promotes the use of fast and frugal heuristics or at least eliminate social norms that are against the use of TTB stopping rule.

The adaptive toolbox has "so called "lower order" perceptual and memory processes which can be fairly automatic, such as depth perception, auditory scene analysis, and face recognition, as well as "higher order" processes that are based on the "lower" processes and can be at least partly accessible to consciousness" (Gigerenzer and Todd, 1999). The effect of social rationality seems to be present at both levels of processes. Our study suggests that choice of heuristic can be influenced by the existence of social norms. An effect of social rationality on the lower level processes can be found in Gladwell's (2007) bestselling book "Blink."

The book, Blink, is about snap judgment – an automated quick decision with little use of information. For example, an expert in fine art spots a forgery at the moment he or she sees it. The part of our brain making such a decision is called "adaptive unconscious," and its mechanism (i.e., how it works) is not clearly known. That is, often times, the expert cannot tell why he or she think the piece is a forgery; he or she is making a decision based on hunch, intuition, etc.

Snap judgment is very accurate, yet it can be altered, undermined, or biased easily by subtle influences. Therefore, it is important to provide an environment, in which the adaptive unconscious can perform best without any biases. An example given by Gladwell is an audition for a spot in the orchestra. Experts in music, such as a conductor, are known to be very good at snap judgment; that is, by listening a few minutes or even seconds of the play of a candidate, they can tell whether or not the candidate is the one whom they are looking for. However, their judgment can be clouded by the gender of a candidate. Before the introduction of a blind audition, there were few women in the orchestra. This was because men were thought to be better than women, especially at certain instruments, such as French hone, trombone, etc. When the screen in the blind audition is removed, judges are often surprised by the fact that they choose women as their top choices.

In the example above, the screen helps block the effect of prejudice, or social norm, so that snap judgment, a lower order process, can perform a bias-free manner. The effect of social norms is so subtle people may not understand or feel such an effect, yet the effect can be very strong in both lower order and higher order processes. Therefore, managers in an organization should examine carefully whether there are any social norms that may negatively affect certain decision processes. If there are, then managers should try to reduce, remove, or block the effects of such norms.

6.5 Limitation and future research

Limitations

The base case in this dissertation is a replica of B. Newell et al.'s (2003) experiment 1, and the value of the dependent variable in the base case was compared with that of each treatment case. However, in each treatment case, there were some factors against the use of the TTB heuristic. This could be problematic especially in the experiment with treatment 1 and 2, where the effects of the treatments are found to be insignificant.

In the experiment with treatment 1, the effect of non-compensatory information was studied on the use of the TTB heuristic. Because the TTB heuristic is a strictly and ecologically rational decision strategy in the environment of non-compensatory information, it should be used if people are adaptive to an environment. However, the experiment with treatment 1 has other factors, such as free information and stock as a stimulus, both of which may not promote the use of the TTB heuristics.

In the experiment with treatment 2, the effect of high perceive information cost was studied, because from the recent experiments of the TTB heuristic, costly information acquisition have been found one of the most influencing factors promoting the use of the TTB heuristic. However, this experiment also has other factors, such as compensatory information and stock as a stimulus, both of which may not promote the use of the TTB heuristics. In sum, the results of the cases of treatment 1 and 2 may have been confounded by the experimental design.

In the experiment with treatment 3, the effect of a social rationality is found to be significant. As in other experiments, this experiment has factors against the use of the TTB heuristic, which are non-compensatory information and free information; yet, the effect of the social rationality turned out to be significant. This can mean the effect the social rationality is very strong. Nevertheless, the cleaner design by employing a better base case will benefit us to understand the effect of these conditions on the use of the TTB heuristic better.

Therefore, we suggest that the better design of a base case than the replica of B. Newell et al.'s (2003) experiment 1 is the one with all known factors that promote the use of the TTB heuristic, or is the one free of the known factors that are against the use of the TTB heuristic. For example, a base case in this dissertation could be the fish selection task with non-compensatory information and non-free information.

Another limitation is the different experimental settings used in the current study compared to the original study by B. Newell et al.'s. We argue that the experimental designs of the past studies are somewhat flawed, and such a conclusion is derived from the comparison between the current study results and those of B. Newell et al.'s. However, the incentives to the participants in each experiment were different, and such a difference may affect the interpretation of the comparison. Real money was rewarded to the participants in B. Newell et al.'s experiments for their performance; therefore, the better performance in the experiments resulted in greater money that the participants could receive. On the other hand, the participants in the current study were told that they would receive the extra credit for the class regardless of their performance. That is, there was no need to excel in the experiments for the benefit they received. However, as Orne (1969) who believed that most participants are good ones who try to confirm what they believe to be the experimental hypothesis (Sawyer, 1975), we believe that the majority, if not all, of the participants in the current experiments are good participants.

Another related change in the experimental settings is the unit of the reward in each trial; English penny was used in the original study, and American dollar was used in the current study. As a result, the cost of information and the reward of correct answer seem to be greater than those of the original study. However, such difference may not be significant because the current experiments used funny money.

Next, external validity of the findings should be discussed. It is related to the generality of the significant effect found in the study. The most relevant factors that threaten the external validity of this study are "interaction of testing and treatment" and "interaction of selection and treatment" (Cook and Campbell, 1975). The assumption of independence of the cues is relevant to the first factor. In the real world, the most valid cue, the second most valid cue, etc. are often not independent; that is, if the most valid cue favors a certain alternative, then the second most valid cue is more likely to favor that alternative. The TTB heuristic is more efficient and works better in such an environment than in the environment of this study, in which the cue are assumed to be independent. This is because cues are somewhat redundant when cues are dependent, and thus the amount of information ignored by the TTB heuristic by using only the non-tied most valid cue is less in an environment with dependent cues than in the experimental environment of this study (Karelaia, 2006). Therefore, we assert that the assumption of independent cues may lower the degree of the use of the TTB heuristic, and the significant effect of social rationality may come out more significant in the real world setting. As far as the effect of social rationality is concerned, we believe the finding can be generalized to the real world well.

The second factor is related to the convenience sample used in this study. All the participants are undergraduate students in a south-eastern US university, that is, not random sampling. Most of the participant are fairly young (mostly between 20 and 25) and lack the experiences of dealing stocks.[4] Therefore, they may have not been exposed much to the social norm that is against the TTB stopping rule, and we believe people in this age group would be similar as far as the social norm is concerned. If true random sampling were used, then there would be more people in the sample who have (direct or indirect) experience of dealing stocks and thus have been affected by the social norm. As a result, the test result of hypothesis 3 would still be significant. All in all, we argue that the effect of social rationality can be generalized to the real world fairly well despite some threats to external validity of the study.

Future research directions

Through the analysis of ecological and social rationality presented in this dissertation, we hope this research can provide more insight into how the adaptive toolbox works. This study suggests various opportunities for future research.

First, future research should develop hypothesis tests for the findings of exploratory analysis. The exploratory findings presented in this dissertation should provide a good starting point for further analysis of interrelationship of three building block of the TTB heuristic. To study under what conditions the TTB heuristic is used, we need to understand when each of the search, stopping and decision rule is followed better. Further, if a certain rule of these three building blocks affect the others and we can isolate the conditions that promote the use of that rule, then we can go one step further to find the condition in which

[4] Based on their answers in post-test questionnaire.

people use the TTB heuristic universally.

Second, this study examines the participants' strategy using a binary classification: TTB vs. others. However, as in B. Newell et al. (2003) and others, future research should examine whether there are meaningful patterns in search, stopping and decision rule for those who did not employ the TTB heuristic. Another interesting and related area is the effect of winning and losing streak. That is, how people respond to an environment when their strategy keeps correct or wrong; will there be any changes in their strategy?

Third, this study provides initial evidence that people employ different strategy for different contexts (e.g., stock vs. fish). Therefore, it is interesting to examine how the TTB heuristic or other similar strategies are used in a choice decision in different contexts, such as a loyal behavior in marketing. For example, when a customer who is loyal to a certain product is asked to choose a better one between her favorite and a new one, we can examine (1) how information is searched, (2) how much information is acquired, and (3) how decision is made.

Lastly, future research should build a better base case as mentioned in the discussion of limitations.

Appendix A

The regression based classification

In the task of paired comparisons, the regression based classification procedure used in Bröder (2000) is an analysis of an individual participant's response vector to find a strategy used in their decision process. The response vector of each participant is the collection of all of his/her choice (e.g., alternative A or B) in the task.

Without loss of generality, the reasoning and procedure of the regression based classification will be explained in the following environment. Each alternative in a paired comparison is described by four binary cues. Values of the cues are coded by either 0 or 1: *Yes* is coded by 1, and *No* is coded 0. For each alternative, there are 16 unique cue patterns, and therefore 120 possible paired comparisons.

First, how the take-the-best (TTB) heuristic is modeled by a multiple regression model is described. If cues, c_1, c_2, c_3 and c_4 are ordered by their validities, a lexicographic order (or rank) of cue pattern j (j = 1, 2, ..., 16) can be expressed by a linear additive model of the cues using non-compensatory weights. For example:

$$\text{Rank}(j) = 8c_{1j} + 4c_{2j} + 2c_{3j} + c_{4j}\,.$$

The TTB alternative is the one that has the higher ranked cue pattern. Let us assume that two alternatives A and B that are described by cue patterns j and k, respectively, where j, $k \in \{1, 2, \ldots, 16\}$ and $j \neq k$. Then, Rank(j) - Rank(k) can tell which one is the TTB alternative according to the following rule:

$$\text{The TTB alternative is } \begin{cases} A, & \text{Rank}(j)>\text{Rank}(k) \\ B, & \text{Rank}(j)<\text{Rank}(k)\,. \end{cases}$$

Let Y be the non-linearly transformed variable of Rank(j) - Rank(k) according to the following transformation rule:

If Rank(j) - Rank(k) > 0, then A; If Rank(j) - Rank(k) < 0, then B.

Then, the following multiple regression model predicts perfectly the behavior of the TTB heuristic:

$$Y = 8d_1 + 4d_2 + 2d_3 + d_4, \text{ where } d_i = c_{ij} - c_{ik}, \begin{cases} i = 1,2,3,4 \\ j,k = 1,2,\cdots,16 \\ j \neq k \end{cases}$$

When a multiple regression model is built by using an individual response vector (Y) as a dependent variable and cue differences (d_i) as independent variable, it will be:

$$\hat{Y} = \hat{B}_0 + \hat{B}_1 d_1 + \hat{B}_2 d_2 + \hat{B}_3 d_3 + \hat{B}_4 d_4 \tag{A.1}$$

If participants follow the TTB heuristic, then $\hat{B}_1 = 2\hat{B}_2 = 4\hat{B}_3 = 8\hat{B}_4$ (TTB null hypothesis). By applying the same logic to the equal weight linear rule (EWL), if participants follow the EWL, then $\hat{B}_1 = \hat{B}_2 = \hat{B}_3 = \hat{B}_4$ (EWL null hypothesis). Testing whether an individual follows the TTB heuristic or not can be achieved by comparing the model fit of the unrestricted model [i.e., equation (A.1)] to the fit of an appropriately restricted model based on the null hypothesis.

However, to apply this method of classification, several conditions must be met. First, a mean of each independent variable (i.e., cue-differences (d_i)) is zero for all i. Second, a variance of each independent variable d_i should be the same for all i. Third, all intercorrelations of d_i are zero. Lastly, all possible paired comparisons must be answered by participants.

Classification is based on the test results of the two null hypotheses. If the TTB hypothesis is accepted and the EWL hypothesis is rejected, then the participant used the TTB heuristic. If the EWL hypothesis is accepted and the TTB hypothesis is rejected, then the participant used EWL. If both hypotheses are rejected, then a non-specified compensatory strategy was used. If both hypotheses are accepted, then an "unclassified" strategy was used.

Appendix B

Calculation of Probability assuming Independence of cues

For cases of paired comparisons, let $(c_i(a), c_i(b))$ denote values of the i^{th} cue for an alternative A and B, where $i = 1, \ldots, n$. For example, if the first cue has "yes" and "no" for an alternative A and B, respectively, then $(c_1(a), c_1(b))$ is (yes, no). Let X denote the correct answer in a comparison. Then, X is either A or B. Let v_i be the validity[1] of a cue c_i; in other words,

$$\begin{aligned} v_i &= P(X = A | c_i(a) = \text{yes}, c_i(b) = \text{no}) = P(X = B | c_i(a) = \text{no}, c_i(b) = \text{yes}) \\ 1 - v_i &= P(X = A | c_i(a) = \text{no}, c_i(b) = \text{yes}) = P(X = B | c_i(a) = \text{yes}, c_i(b) = \text{no}) \end{aligned}$$

The probability $P(X = A|\mathbf{C})$ represents the probability of an alternative A being a correct answer given a cue pattern $\mathbf{C} = ((c_1(a), c_1(b)), \ldots, (c_n(a), c_n(b)))$. Then, to determine whether information is compensatory or non-compensatory, calculation of the probability $P(X = A|\mathbf{C})$ is required.

In this dissertation and other empirical studies concerning the TTB heuristic (e.g., Bröder, 2000; Newell et al., 2003; Newell and Shanks, 2003), the calculation of $P(X = A|\mathbf{C})$ is done based on the assumption that cues are independent of each other. The model with such an assumption has been called by many different names, such as idiot's Bayes,

[1] also see the discussion on validity on page 28.

naive Bayes, simple Bayes, and independent Bayes (Hand and Yu, 2001). With this assumption,

$$P(\mathbf{C}|X=A) = \prod_{i=1}^{n} P((c_i(a), c_i(b))|X=A)\,.$$

In the independence model, calculation of $P(X=A|\mathbf{C})$ is done based the estimation of the odd of A being correct answer

$$\text{odds}(A) \quad = \quad \frac{P(X=A|\mathbf{C})}{1-P(X=A|\mathbf{C})} = \frac{P(X=A|\mathbf{C})}{P(X=B|\mathbf{C})}\,. \tag{B.1}$$

The equation B.1 can be rewritten as follows:

$$\begin{aligned}
\frac{P(X=A|\mathbf{C})}{P(X=B|\mathbf{C})} &= \frac{P(X=A)P(\mathbf{C}|X=A)}{P(X=B)P(\mathbf{C}|X=B)} \\
&= \frac{P(X=A)\prod_{i=1}^{n} P((c_i(a), c_i(b))|X=A)}{P(X=B)\prod_{i=1}^{n} P((c_i(a), c_i(b))|X=A)} \\
&= \frac{P(X=A)P(c_1(a), c_1(b)|X=A) * \cdots * P(c_n(a), c_n(b)|X=A)}{P(X=B)P(c_1(a), c_1(b)|X=B) * \cdots * P(c_n(a), c_n(b)|X=B)} \\
&= \frac{P(X=A)}{P(X=B)} * \frac{P(c_1(a), c_1(b)|X=A)}{P(c_1(a), c_1(b)|X=B)} * \cdots * \frac{P(c_n(a), c_n(b)|X=A)}{P(c_n(a), c_n(b)|X=B)}
\end{aligned} \tag{B.2}$$

Note that $P(c_i(a), c_i(b)|X=A)/P(c_i(a), c_i(b)|X=B)$ in equation B.2 is a likelihood ratio A to B, that is, the degree to which cue i supports A as a correct answer. Therefore, if this value is greater than 1, then the cue c_i supports A against B as a correct answer; if this value is less than 1, then the cue c_i supports B against A.

In this dissertation and other studies, the prior probabilities $P(X=A)$ and $P(X=B)$ are the same at 0.5. Therefore, from the equation B.2, the odd ratio is simply the product of n likelihood ratios. The likelihood ratio can be rewritten as follow:

$$\begin{aligned}
\frac{P(c_i(a), c_i(b)|X=A)}{P(c_i(a), c_i(b)|X=B)} &= \frac{P(X=A|c_i(a), c_i(b)) * P(c_i(a), c_i(b))/P(X=A)}{P(X=B|c_i(a), c_i(b)) * P(c_i(a), c_i(b))/P(X=B)} \\
&= \frac{P(X=A|c_i(a), c_i(b))}{P(X=B|c_i(a), c_i(b))} \\
&= \frac{P(X=A|c_i(a), c_i(b))}{1-P(X=A|c_i(a), c_i(b))}
\end{aligned} \tag{B.3}$$

Note that if $c_i(a) = c_i(b)$, then $P(X = A|c_i(a), c_i(b)) = P(X = B|c_i(a), c_i(b)) = 0.5$; that is, the likelihood ratio will be one. From equation B.3, the odds(A) is

$$\prod_{i=1}^{n} \frac{P(X = A|c_i(a), c_i(b))}{1 - P(X = A|c_i(a), c_i(b))}, \tag{B.4}$$

and the probability $P(X = A|\mathbf{C})$ is

$$\frac{\text{odds}(A)}{1 + \text{odds}(A)}.$$

B.1 Example

In B. Newell et al.'s (2003) experiment 1, validities of six cue are 0.90, 0.85, 0.80, 0.75, 0.70, and 0.65. The odds of A being a correct answer given the cue pattern shown in table B.1 can be calculated as follows:

$$\begin{aligned}
\text{odds}(A) &= \frac{v_1}{1-v_1} * \frac{v_2}{1-v_2} * \frac{1-v_3}{v_3} * \frac{1-v_4}{v_4} * \frac{1-v_5}{v_5} * \frac{1-v_6}{v_6} \\
&= \frac{0.90}{0.10} * \frac{0.85}{0.15} * \frac{0.20}{0.80} * \frac{0.25}{0.75} * \frac{0.30}{0.70} * \frac{0.35}{0.65} \\
&= \frac{4016}{4095} \\
&= 0.98.
\end{aligned}$$

Then, the probability of A being a correct answer give the cue pattern is

$$P(X = A|\mathbf{C}) = \frac{0.98}{1 + 0.98} = 0.495.$$

Cue	A	B	Validity (v_i)
c_1	Yes	No	0.90
c_2	Yes	No	0.85
c_3	No	Yes	0.80
c_4	No	Yes	0.75
c_5	No	Yes	0.70
c_6	No	Yes	0.65

Table B.1: An example of cue pattern

B.2 Compensatory vs. non-compensatory information

Non-compensatory information refers to the environment in which each cue is more important than any combination of less valid cues.[2] Using probability, it means once the non-tied most valid cue favors an alternative A, then $P(X = A|\mathbf{C})$ should be greater than or equal to 0.5 for any cue patterns. In the example shown in section B.1, the non-tied most valid cue is c_1, which favors an alternative A. However, $P(X = A|\mathbf{C})$ = 0.495 < 0.5. Therefore, the cue validity used in B. Newell et al.'s (2003) experiment 1 represent compensatory information.

An easier way of determining whether the information is compensatory or non-compensatory is to use the odds(A). For any cue pattern, the odds(A) should be greater than or equal to 1 in non-compensatory environment, otherwise information is compensatory. That is because if the odds(A) is 1 or greater, the $P(X = A|\mathbf{C})$ will be 0.5 or greater. In the example in section B.1, since the odds(A) is less 1, the information structure is compensatory.

Let us take a look the extreme case in which only one cue favors A and the rest of less valid cue favors B. Let $i = 1, \ldots, n$ be the rank of cues based on their validity. When all cues in $\{c_i | i < j,\ 1 \leq j \leq n-1\}$ are tied, c_j favors A, and all the less valid cues $\{c_i | j < i \leq n\}$ favors B, the odds(A) is

$$\frac{v_j}{1-v_j}\prod_{i=j+1}^{n}\frac{1-v_i}{v_i}\,. \tag{B.5}$$

Then, the value of equation B.5 should be greater than 1 for all $1 \leq j \leq n-1$ in non-compensatory environment;[3] otherwise, the environment is compensatory.

[2] see page 20.

[3] If $j = n$, then it is trivial; the information is non-compensatory.

Appendix C

Definitions of validity used in other papers

“The validity v_i of the ith cue is

$$v_i = P[t(a) > t(b) | a_i \text{ is positive and } b_i \text{ is negative}] \,,$$

where $t(a)$ and $t(b)$ are the values of objects a and b on the target variable t and p is a probability measured as a relative frequency in R.” (Gigerenzer and Goldstein, 1996, p. 654/655)

“Following Gigerenzer and Goldstein (1996a) we define the ecological validity of a cue as the proportion of right inferences:

$$v = \frac{R}{R+W} \,,$$

where R denotes the number of right inferences and W denotes the number of wrong inferences.” (Martignon and Hoffrage, 1999, p. 130)

“Since Prob$(X_a > X_b | C_i(a), C_j(b))$ is ecological validity ...” (Martignon, 1999, p. 179)

“... validity is defined as the probability that the cue will identify the correct alternative on a random selection of alternatives that differ on this cue.” (Newell et al., 2003, p. 85)

Appendix D

Program code

Ten forms and one module are used for every experiment. The sequence of the forms are illustrated in figure D.1; each rectangular represent a form, and the inputs to the shared forms are provided by the experimenter. The inputs to all other forms, if required, are provided by the participant.

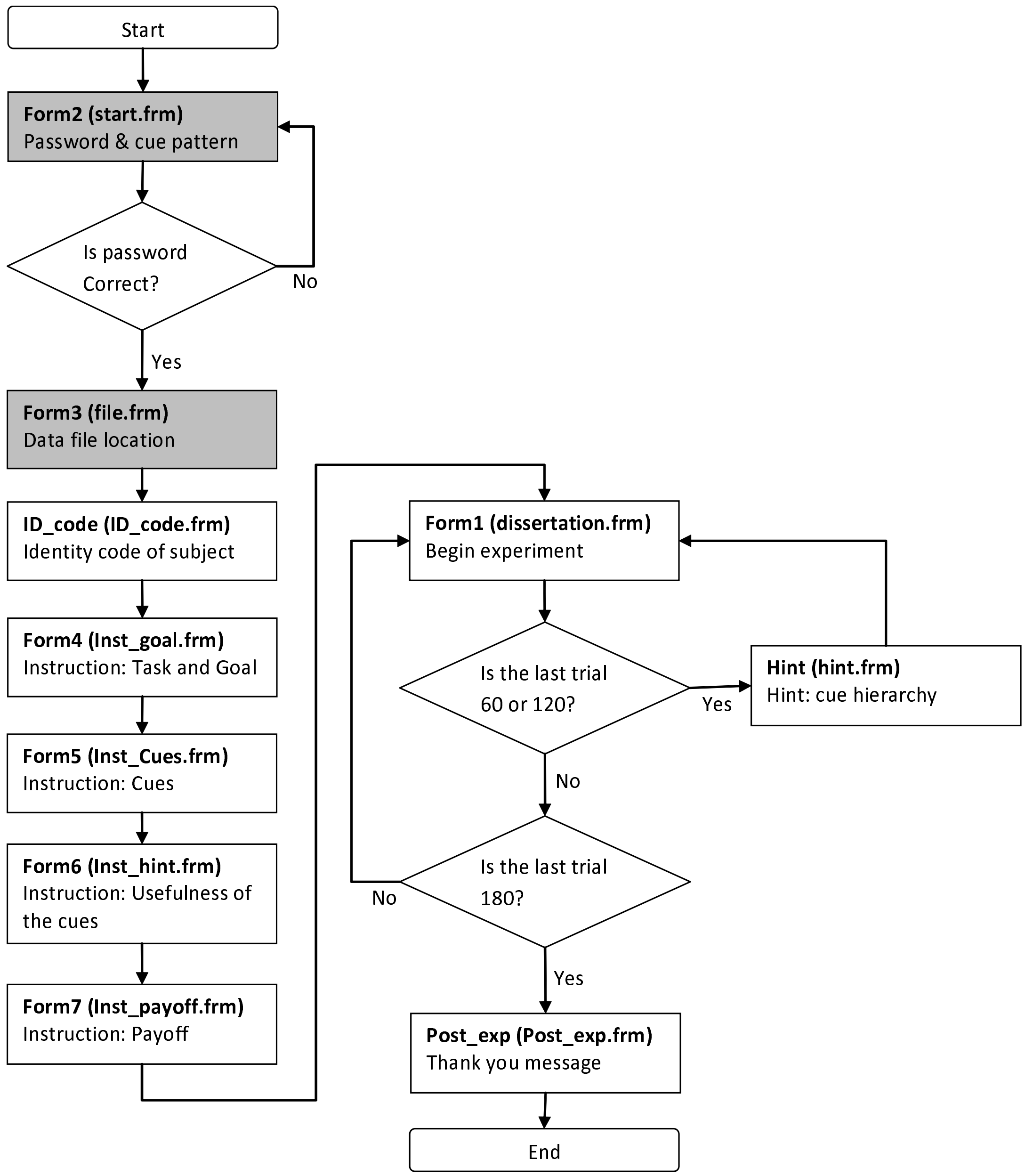
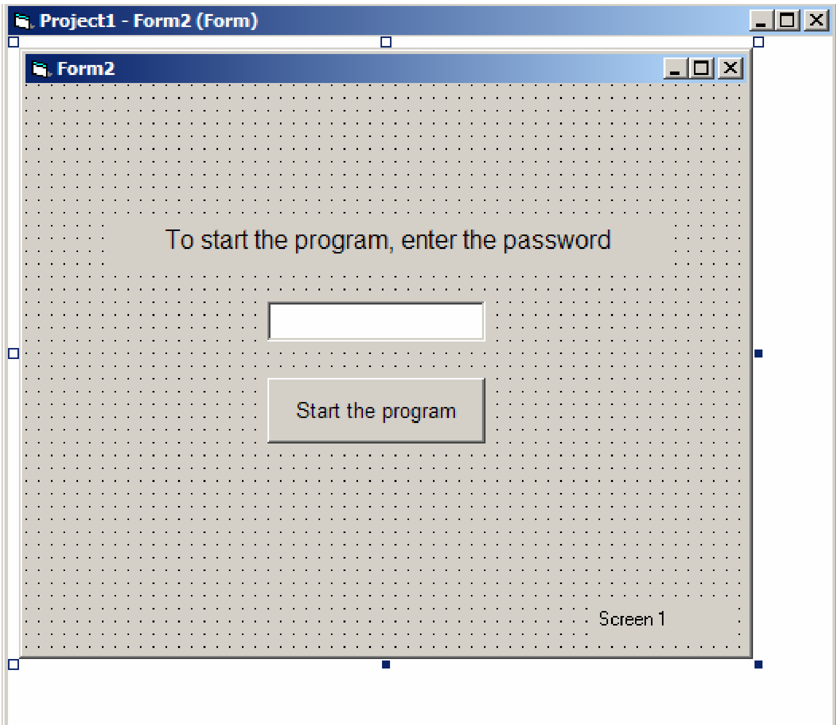


Figure D.1: Sequence of the forms

D.1 Base case

D.1.1 From2 (start.frm)

Form

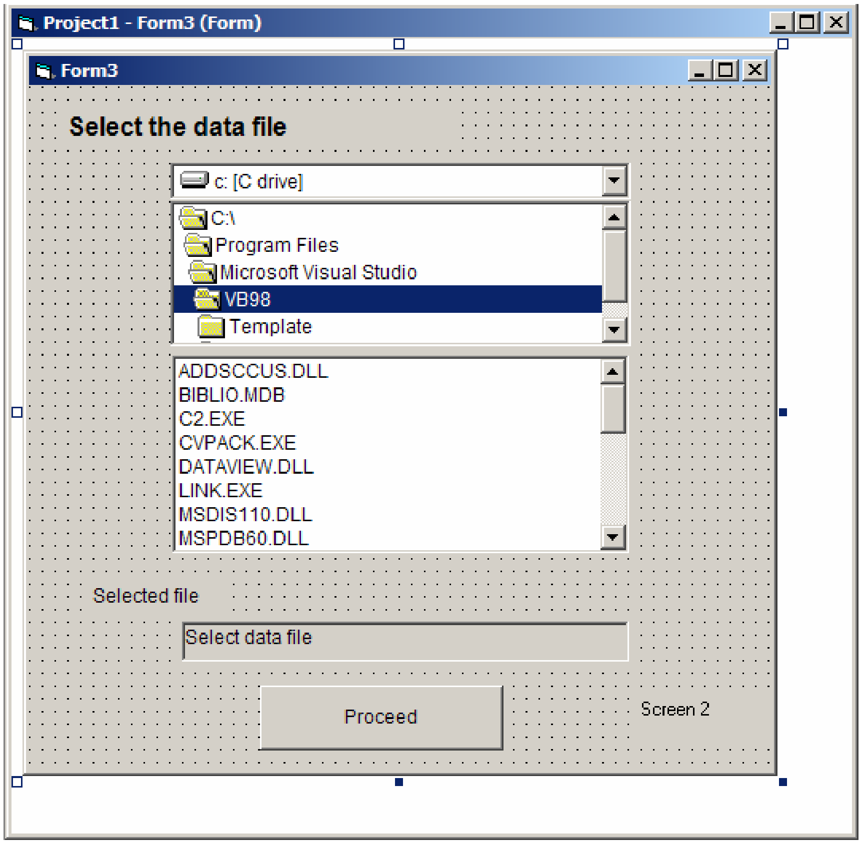


Code

```
Private Sub cmdShowForm1_Click()
  If Text1.Text = "0000" Then
    selected = InputBox("cue pattern number (0-49)")
    total_trial = 180
    Form3.Show
    Unload Me
  Else
    Text1.Text = ""
  End If
End Sub
Private Sub Form_Load()
Randomize
  Text1.Text = ""
  Text1.PasswordChar = "*"
End Sub
```

D.1.2 Form3 (files.frm)

Form

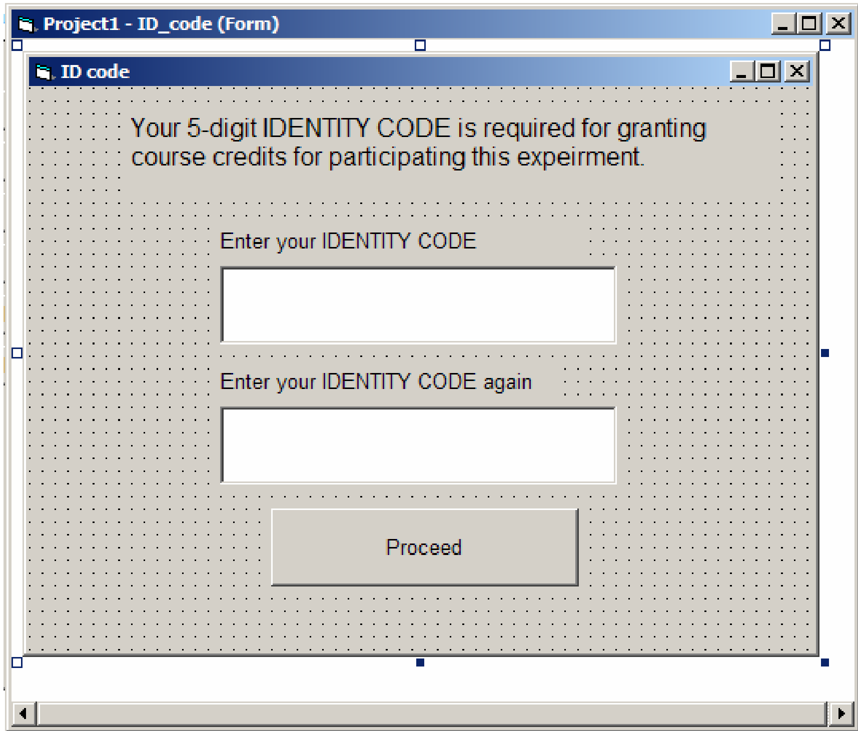


Code

```
Private Sub Command1_Click()
    If File1.FileName = "data.txt" Then
        ID_code.Show
        Unload Me
    End If
End Sub

Private Sub Drive1_Change()
    Dir1.Path = Drive1.Drive
End Sub

Private Sub Dir1_Change()
    File1.FileName = Dir1.Path
End Sub

Private Sub File1_Click()
    outputfolder = File1.Path
    If Right(outputfolder, 1) <> "\" Then
        outputfolder = outputfolder & "\"
    End If
    datafile = outputfolder & File1.FileName
    Label2.Caption = datafile
End Sub
```

D.1.3 ID_code (ID_code.frm)

Form

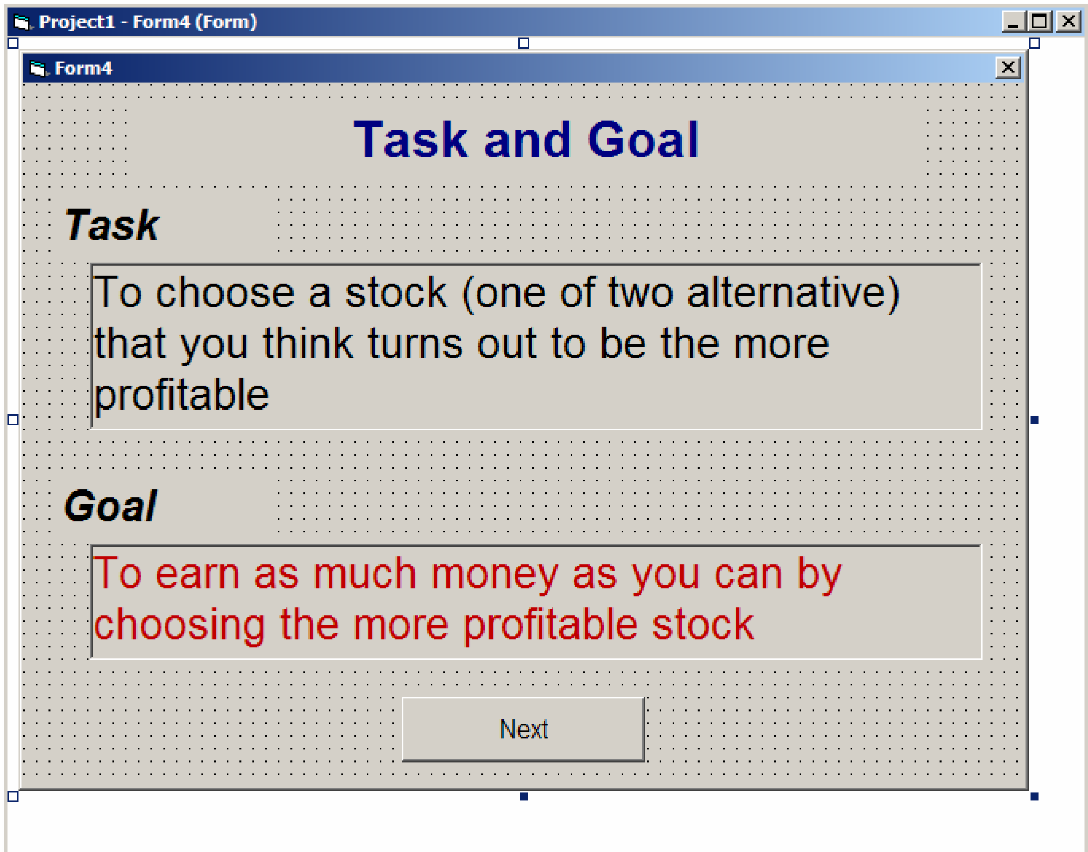


Code

```
Private Sub Command1_Click()
If Text1.Text = "" Then
    MsgBox ("Please enter Identity code.")
ElseIf Text1.Text = Text2.Text Then
    IDcode = Text1.Text
    Form4.Show
    Unload Me
Else
    Text1.Text = ""
    Text2.Text = ""
End If
End Sub
```

D.1.4 Form4 (Inst_goal.frm)

Form

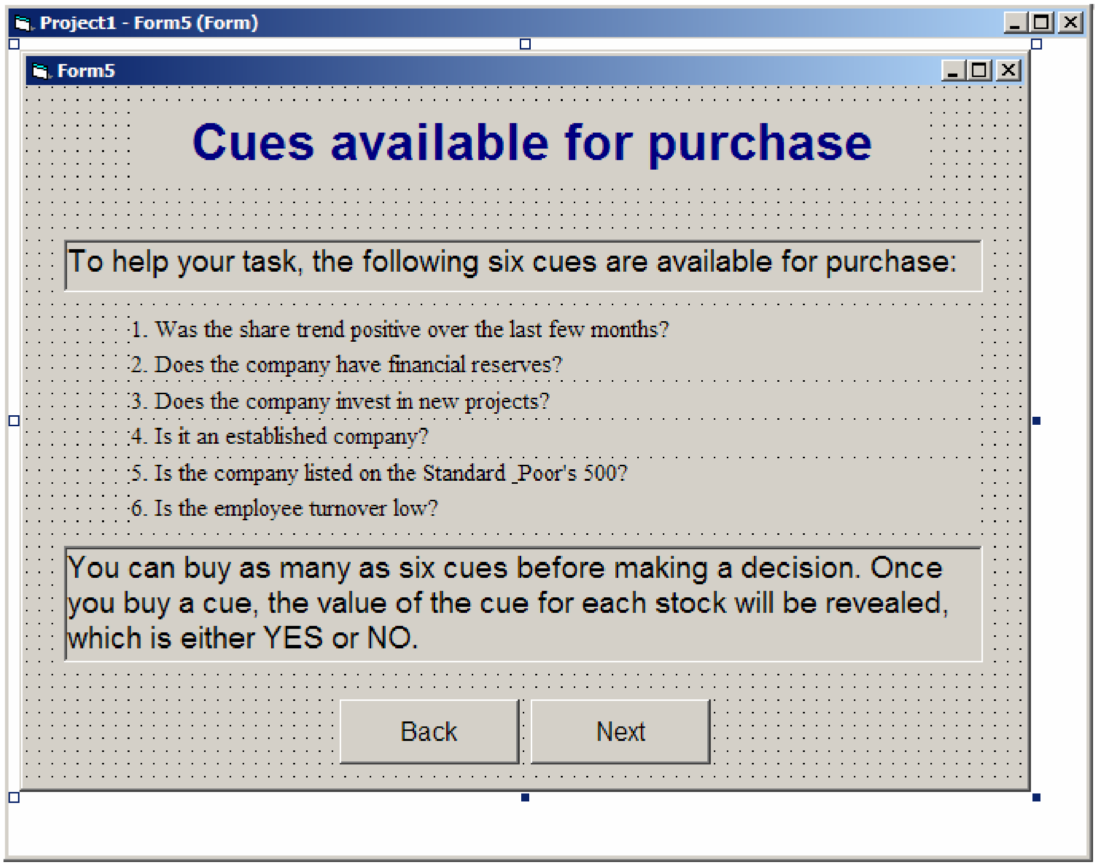


Code

```
Private Sub Command1_Click()
    Form5.Show
    Unload Me
End Sub
```

D.1.5 Form5 (Inst_Cues.frm)

Form

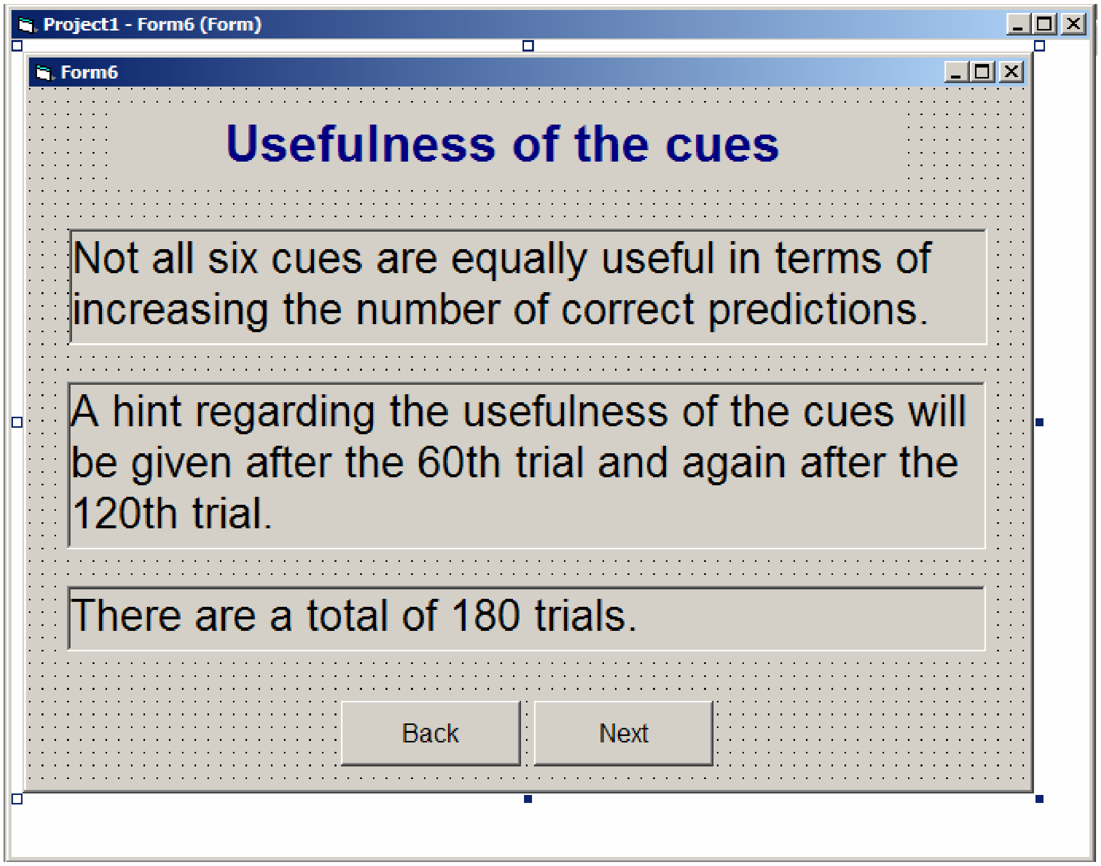


Code

```
Private Sub Command1_Click()
    Form6.Show
    Unload Me
End Sub

Private Sub Command2_Click()
Form4.Show
Unload Me
End Sub
```

D.1.6 Form6 (Inst_hint.frm)

Form

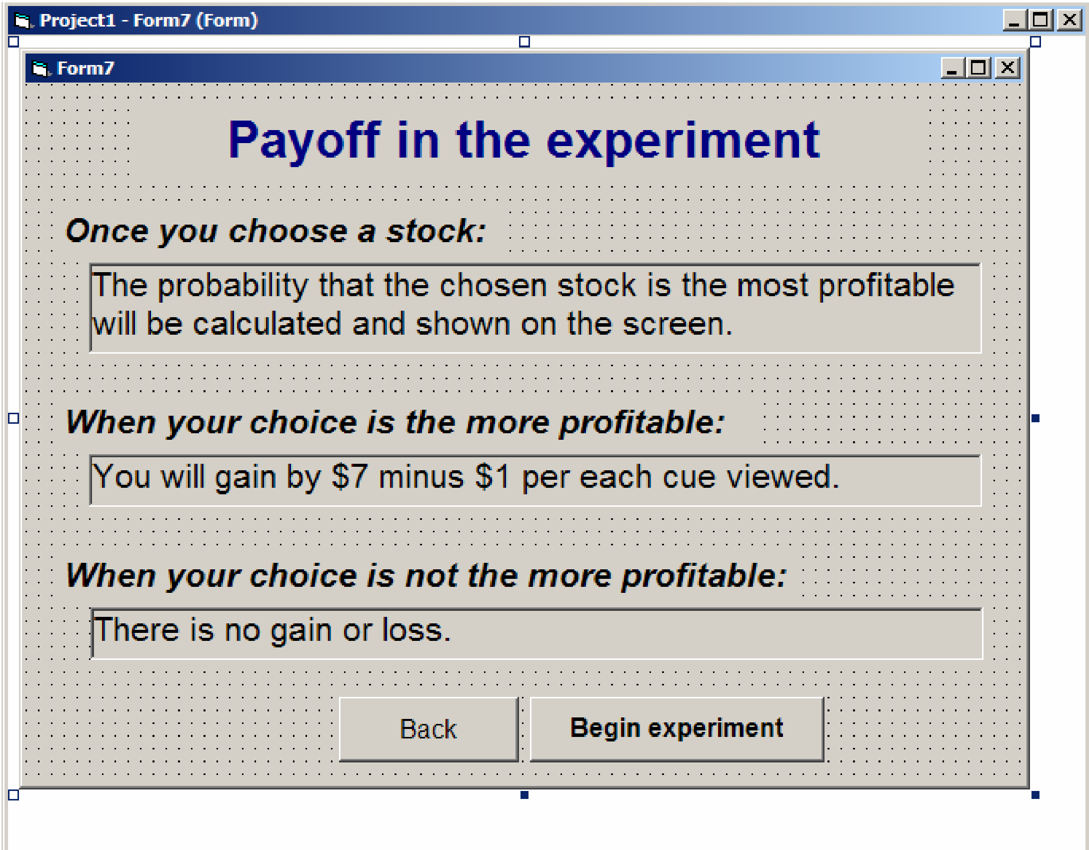


Code

```
Private Sub Command1_Click()
    Form7.Show
    Unload Me
End Sub

Private Sub Command2_Click()
Form5.Show
Unload Me
End Sub
```

D.1.7 Form7 (Inst_payoff.frm)

Form

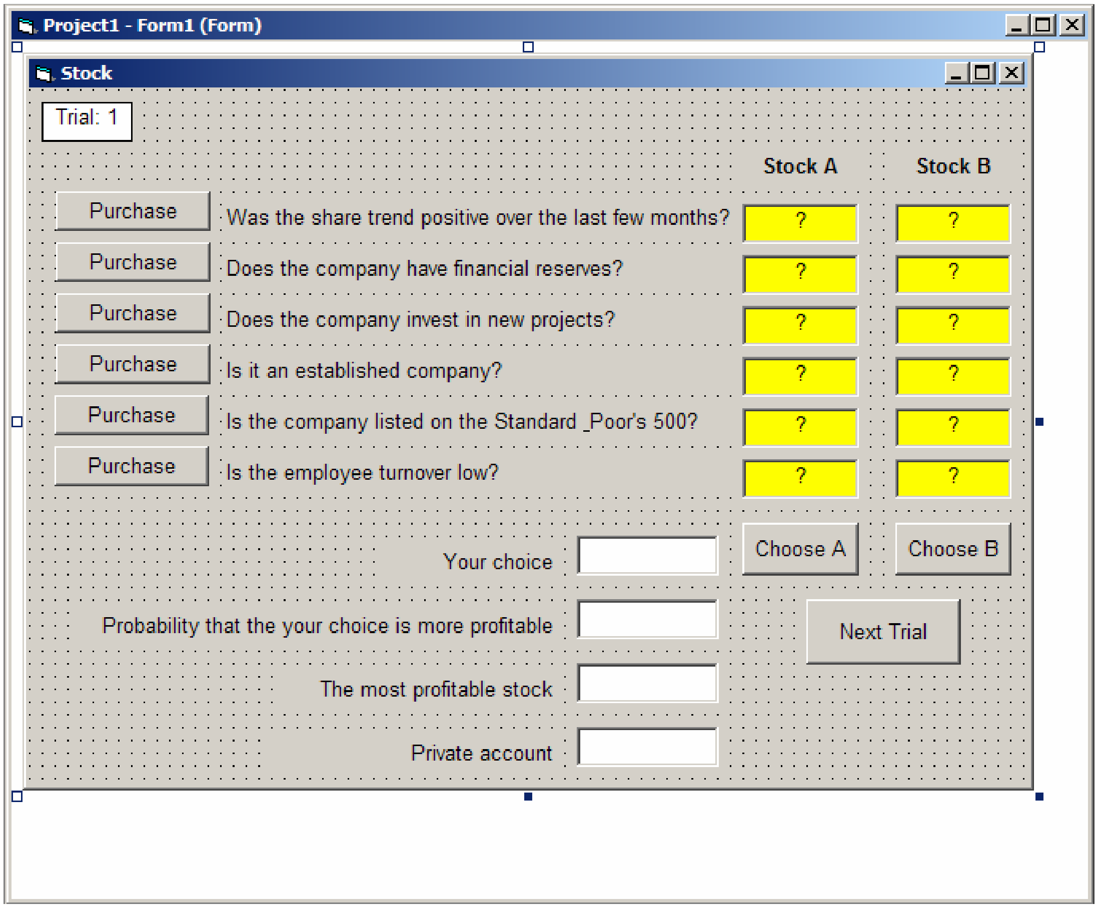


Code

```
Private Sub Command1_Click()
    Form1.Show
    Unload Me
End Sub

Private Sub Command2_Click()
Form6.Show
Unload Me
End Sub
```

D.1.8 Form1 (dissertation.frm)

Form



Code

```
'Buy cues and assign cue values
Private Sub cmdCue1_Click()
    If lblChoiceVal = "" And lblCue1A.Caption = "?" Then
        lblCue1A.Caption = C1A(trial)
        lblCue1B.Caption = C1B(trial)

        'online ranking
        If rank1(selected) = 1 Then
            ORK(trial, cue) = 1
        ElseIf rank2(selected) = 1 Then
            ORK(trial, cue) = 2
        ElseIf rank3(selected) = 1 Then
            ORK(trial, cue) = 3
        ElseIf rank4(selected) = 1 Then
            ORK(trial, cue) = 4
        ElseIf rank5(selected) = 1 Then
            ORK(trial, cue) = 5
        Else
            ORK(trial, cue) = 6
        End If

        cue = cue + 1
        C1(trial) = cue

        lblAccountVal.Caption = FormatCurrency(money + 1000)

        If nontiedcue <> "" Then
            uncue = uncue + 1
```

```
        End If

        If lblCue1A.Caption <> lblCue1B.Caption And nontiedcue = "" Then
            nontiedcue = 1
            nontiedcue_num = cue
            If lblCue1A.Caption = "Yes" Then
                ini_direction = "A"
            Else
                ini_direction = "B"
            End If
        End If
    End If

End Sub
Private Sub cmdCue2_Click()
    If lblChoiceVal = "" And lblCue2A.Caption = "?" Then
        lblCue2A.Caption = C2A(trial)
        lblCue2B.Caption = C2B(trial)

        'online ranking
        If rank1(selected) = 2 Then
            ORK(trial, cue) = 1
        ElseIf rank2(selected) = 2 Then
            ORK(trial, cue) = 2
        ElseIf rank3(selected) = 2 Then
            ORK(trial, cue) = 3
        ElseIf rank4(selected) = 2 Then
            ORK(trial, cue) = 4
        ElseIf rank5(selected) = 2 Then
            ORK(trial, cue) = 5
        Else
            ORK(trial, cue) = 6
        End If
        cue = cue + 1
        C2(trial) = cue
        'money = money - 1
        lblAccountVal.Caption = FormatCurrency(money + 1000)


        If nontiedcue <> "" Then
            uncue = uncue + 1
        End If


        If lblCue2A.Caption <> lblCue2B.Caption And nontiedcue = "" Then
            nontiedcue = 2
            nontiedcue_num = cue
            If lblCue2A.Caption = "Yes" Then
                ini_direction = "A"
            Else
                ini_direction = "B"
            End If
        End If
    End If
End Sub
Private Sub cmdCue3_Click()
    If lblChoiceVal = "" And lblCue3A.Caption = "?" Then
        lblCue3A.Caption = C3A(trial)
        lblCue3B.Caption = C3B(trial)

        'online ranking
        If rank1(selected) = 3 Then
            ORK(trial, cue) = 1
        ElseIf rank2(selected) = 3 Then
            ORK(trial, cue) = 2
        ElseIf rank3(selected) = 3 Then
            ORK(trial, cue) = 3
        ElseIf rank4(selected) = 3 Then
            ORK(trial, cue) = 4
        ElseIf rank5(selected) = 3 Then
            ORK(trial, cue) = 5
        Else
            ORK(trial, cue) = 6
        End If
        cue = cue + 1
        C3(trial) = cue
        'money = money - 1
        lblAccountVal.Caption = FormatCurrency(money + 1000)

        If nontiedcue <> "" Then
            uncue = uncue + 1
        End If

        If lblCue3A.Caption <> lblCue3B.Caption And nontiedcue = "" Then
            nontiedcue = 3
            nontiedcue_num = cue
            If lblCue3A.Caption = "Yes" Then
                ini_direction = "A"
            Else
                ini_direction = "B"
            End If
        End If
```

```
    End If
End Sub
Private Sub cmdCue4_Click()
    If lblChoiceVal = "" And lblCue4A.Caption = "?" Then
        lblCue4A.Caption = C4A(trial)
        lblCue4B.Caption = C4B(trial)

        'online ranking
        If rank1(selected) = 4 Then
            ORK(trial, cue) = 1
        ElseIf rank2(selected) = 4 Then
            ORK(trial, cue) = 2
        ElseIf rank3(selected) = 4 Then
            ORK(trial, cue) = 3
        ElseIf rank4(selected) = 4 Then
            ORK(trial, cue) = 4
        ElseIf rank5(selected) = 4 Then
            ORK(trial, cue) = 5
        Else
            ORK(trial, cue) = 6
        End If
        cue = cue + 1
        C4(trial) = cue
        'money = money - 1
        lblAccountVal.Caption = FormatCurrency(money + 1000)

        If nontiedcue <> "" Then
            uncue = uncue + 1
        End If

        If lblCue4A.Caption <> lblCue4B.Caption And nontiedcue = "" Then
            nontiedcue = 4
            nontiedcue_num = cue
            If lblCue4A.Caption = "Yes" Then
                ini_direction = "A"
            Else
                ini_direction = "B"
            End If
        End If
    End If
End Sub
Private Sub cmdCue5_Click()
    If lblChoiceVal = "" And lblCue5A.Caption = "?" Then
        lblCue5A.Caption = C5A(trial)
        lblCue5B.Caption = C5B(trial)

        'online ranking
        If rank1(selected) = 5 Then
            ORK(trial, cue) = 1
        ElseIf rank2(selected) = 5 Then
            ORK(trial, cue) = 2
        ElseIf rank3(selected) = 5 Then
            ORK(trial, cue) = 3
        ElseIf rank4(selected) = 5 Then
            ORK(trial, cue) = 4
        ElseIf rank5(selected) = 5 Then
            ORK(trial, cue) = 5
        Else
            ORK(trial, cue) = 6
        End If

        cue = cue + 1
        C5(trial) = cue
        'money = money - 1
        lblAccountVal.Caption = FormatCurrency(money + 1000)

        If nontiedcue <> "" Then
            uncue = uncue + 1
        End If


        If lblCue5A.Caption <> lblCue5B.Caption And nontiedcue = "" Then
            nontiedcue = 5
            nontiedcue_num = cue
            If lblCue5A.Caption = "Yes" Then
                ini_direction = "A"
            Else
                ini_direction = "B"
            End If
        End If
    End If
End Sub
Private Sub cmdCue6_Click()
    If lblChoiceVal = "" And lblCue6A.Caption = "?" Then
        lblCue6A.Caption = C6A(trial)
        lblCue6B.Caption = C6B(trial)

        'online ranking
        If rank1(selected) = 6 Then
            ORK(trial, cue) = 1
        ElseIf rank2(selected) = 6 Then
            ORK(trial, cue) = 2
```

```
        ElseIf rank3(selected) = 6 Then
            ORK(trial, cue) = 3
        ElseIf rank4(selected) = 6 Then
            ORK(trial, cue) = 4
        ElseIf rank5(selected) = 6 Then
            ORK(trial, cue) = 5
        Else
            ORK(trial, cue) = 6
        End If

        cue = cue + 1
        C6(trial) = cue
        'money = money - 1
        lblAccountVal.Caption = FormatCurrency(money + 1000)

        If nontiedcue <> "" Then
            uncue = uncue + 1
        End If

        If lblCue6A.Caption <> lblCue6B.Caption And nontiedcue = "" Then
            nontiedcue = 6
            nontiedcue_num = cue
            If lblCue6A.Caption = "Yes" Then
                ini_direction = "A"
            Else
                ini_direction = "B"
            End If
        End If
    End If
End Sub
'When choose A or B, assign the chosen share in Your Choice
Private Sub cmdStockA_Click()
    If lblChoiceVal.Caption = "" Then
        'answer = MsgBox("Your choice is stock A.", vbQuestion + vbYesNo, "Confirm your choice")
        'If answer = vbYes Then
            lblChoiceVal.Caption = "A"
            lblProbVal.Caption = FormatNumber(prob(trial), 4)
            p_ans(trial) = "A"
            ' Put more stuff here
        'Else
         '   txtChoice.Text = ""

        'timer related
        Finishtime(trial) = Now

        'Random number generator decide which cue is the more profitable one
        If Rnd < prob(trial) Then
            lblAnswerVal.Caption = "A"
        Else
            lblAnswerVal.Caption = "B"
        End If

        'determine prize money
        If lblAnswerVal.Caption = "A" Then
            money = money + 7 - cue
            lblAccountVal.Caption = FormatCurrency(money + 1000)
            ' 1 = correct and 0 = wrong
            correct(trial) = 1
        Else

            lblAccountVal.Caption = FormatCurrency(money + 1000)
            correct(trial) = 0
        End If

    Else
        MsgBox ("You have already made a choice!")
    End If
End Sub
Private Sub cmdStockB_Click()
    If lblChoiceVal.Caption = "" Then
        'answer = MsgBox("Your choice is stock A.", vbQuestion + vbYesNo, "Confirm your choice")
        'If answer = vbYes Then
            lblChoiceVal.Caption = "B"
            lblProbVal.Caption = FormatNumber(1 - prob(trial), 4)
            p_ans(trial) = "B"
            ' Put more stuff here
        'Else
         '   txtChoice.Text = ""

        Finishtime(trial) = Now

        'Random number generator decide which cue is the more profitable one

        If Rnd < 1 - prob(trial) Then
            lblAnswerVal.Caption = "B"
        Else
            lblAnswerVal.Caption = "A"
        End If


        If lblAnswerVal.Caption = "B" Then
            money = money + 7 - cue
```

```
            lblAccountVal.Caption = FormatCurrency(money + 1000)
            ' 1 = correct and 0 = wrong
            correct(trial) = 1
        Else
            lblAccountVal.Caption = FormatCurrency(money + 1000)
            correct(trial) = 0
        End If

    Else
        MsgBox ("You have already made a choice!")
    End If
End Sub
Private Sub cmdNext_Click()
    If lblChoiceVal.Caption = "" Then
        MsgBox ("Please select a stock.")
    ElseIf trial < (total_trial / 3 - 1) Then
        '180 trials
        'reset the cue values to ?
        lblCue1A.Caption = "?"
        lblCue1B.Caption = "?"
        lblCue2A.Caption = "?"
        lblCue2B.Caption = "?"
        lblCue3A.Caption = "?"
        lblCue3B.Caption = "?"
        lblCue4A.Caption = "?"
        lblCue4B.Caption = "?"
        lblCue5A.Caption = "?"
        lblCue5B.Caption = "?"
        lblCue6A.Caption = "?"
        lblCue6B.Caption = "?"

        lblChoiceVal.Caption = ""
        lblProbVal.Caption = ""
        lblAnswerVal.Caption = ""

        'timer related
        ElapsedTime(trial) = DateDiff("s", BeginTime(trial), Finishtime(trial))
        BeginTime(trial + 1) = Now

        Open outputfolder & "output_ex1_" & IDcode & "_" & selected & ".txt" For Append As #2
        Write #2, trial + 1, C1(trial), C2(trial), C3(trial), C4(trial), C5(trial), C6(trial), _
                  ORK(trial, 0), ORK(trial, 1), ORK(trial, 2), ORK(trial, 3), ORK(trial, 4), ORK(trial, 5), _
                  nontiedcue, nontiedcue_num, uncue, ini_direction, correct(trial), p_ans(trial), order(trial), _
                  ElapsedTime(trial), BeginTime(trial), Finishtime(trial)
        Close #2
        trial = trial + 1
        lblTrial.Caption = "Trial: " & trial + 1



        'If money = "" Then
        '    lblAccountVal.Caption = FormatCurrency(0)
        'Else
            lblAccountVal.Caption = FormatCurrency(money + 1000)
        'End If

        cue = 0
        uncue = 0
        nontiedcue = ""
        nontiedcue_num = 0
        ini_direction = ""

    ElseIf trial = (total_trial / 3 - 1) Then

        lblCue1A.Caption = "?"
        lblCue1B.Caption = "?"
        lblCue2A.Caption = "?"
        lblCue2B.Caption = "?"
        lblCue3A.Caption = "?"
        lblCue3B.Caption = "?"
        lblCue4A.Caption = "?"
        lblCue4B.Caption = "?"
        lblCue5A.Caption = "?"
        lblCue5B.Caption = "?"
        lblCue6A.Caption = "?"
        lblCue6B.Caption = "?"

        lblChoiceVal.Caption = ""
        lblProbVal.Caption = ""
        lblAnswerVal.Caption = ""

        'timer related
        ElapsedTime(trial) = DateDiff("s", BeginTime(trial), Finishtime(trial))
        BeginTime(trial + 1) = Now

        Open outputfolder & "output_ex1_" & IDcode & "_" & selected & ".txt" For Append As #2
        Write #2, trial + 1, C1(trial), C2(trial), C3(trial), C4(trial), C5(trial), C6(trial), _
                  ORK(trial, 0), ORK(trial, 1), ORK(trial, 2), ORK(trial, 3), ORK(trial, 4), ORK(trial, 5), _
                  nontiedcue, nontiedcue_num, uncue, ini_direction, correct(trial), p_ans(trial), order(trial), _
                  ElapsedTime(trial), BeginTime(trial), Finishtime(trial)
        Close #2
```

```
    trial = trial + 1
    lblTrial.Caption = "Trial: " & trial + 1

    'If money = "" Then
    '    lblAccountVal.Caption = FormatCurrency(0)
    'Else
        lblAccountVal.Caption = FormatCurrency(money + 1000)
    'End If

    cue = 0
    uncue = 0
    nontiedcue = ""
    nontiedcue_num = 0
    ini_direction = ""

    Hint.Show
    Form1.Hide

ElseIf trial < (2 * total_trial / 3 - 1) Then
    '180 trials
    'reset the cue values to ?
    lblCue1A.Caption = "?"
    lblCue1B.Caption = "?"
    lblCue2A.Caption = "?"
    lblCue2B.Caption = "?"
    lblCue3A.Caption = "?"
    lblCue3B.Caption = "?"
    lblCue4A.Caption = "?"
    lblCue4B.Caption = "?"
    lblCue5A.Caption = "?"
    lblCue5B.Caption = "?"
    lblCue6A.Caption = "?"
    lblCue6B.Caption = "?"

    lblChoiceVal.Caption = ""
    lblProbVal.Caption = ""
    lblAnswerVal.Caption = ""

    'timer related
    ElapsedTime(trial) = DateDiff("s", BeginTime(trial), Finishtime(trial))
    BeginTime(trial + 1) = Now

    Open outputfolder & "output_ex1_" & IDcode & "_" & selected & ".txt" For Append As #2
    Write #2, trial + 1, C1(trial), C2(trial), C3(trial), C4(trial), C5(trial), C6(trial), _
              ORK(trial, 0), ORK(trial, 1), ORK(trial, 2), ORK(trial, 3), ORK(trial, 4), ORK(trial, 5), _
              nontiedcue, nontiedcue_num, uncue, ini_direction, correct(trial), p_ans(trial), order(trial), _
              ElapsedTime(trial), BeginTime(trial), Finishtime(trial)
    Close #2

    trial = trial + 1
    lblTrial.Caption = "Trial: " & trial + 1

    'If money = "" Then
    '    lblAccountVal.Caption = FormatCurrency(0)
    'Else
        lblAccountVal.Caption = FormatCurrency(money + 1000)
    'End If

    cue = 0
    uncue = 0
    nontiedcue = ""
    nontiedcue_num = 0
    ini_direction = ""

ElseIf trial = (2 * total_trial / 3 - 1) Then
    lblCue1A.Caption = "?"
    lblCue1B.Caption = "?"
    lblCue2A.Caption = "?"
    lblCue2B.Caption = "?"
    lblCue3A.Caption = "?"
    lblCue3B.Caption = "?"
    lblCue4A.Caption = "?"
    lblCue4B.Caption = "?"
    lblCue5A.Caption = "?"
    lblCue5B.Caption = "?"
    lblCue6A.Caption = "?"
    lblCue6B.Caption = "?"

    lblChoiceVal.Caption = ""
    lblProbVal.Caption = ""
    lblAnswerVal.Caption = ""

    'timer related
    ElapsedTime(trial) = DateDiff("s", BeginTime(trial), Finishtime(trial))
    BeginTime(trial + 1) = Now

    Open outputfolder & "output_ex1_" & IDcode & "_" & selected & ".txt" For Append As #2
    Write #2, trial + 1, C1(trial), C2(trial), C3(trial), C4(trial), C5(trial), C6(trial), _
              ORK(trial, 0), ORK(trial, 1), ORK(trial, 2), ORK(trial, 3), ORK(trial, 4), ORK(trial, 5), _
              nontiedcue, nontiedcue_num, uncue, ini_direction, correct(trial), p_ans(trial), order(trial), _
              ElapsedTime(trial), BeginTime(trial), Finishtime(trial)
```

```
        Close #2


        trial = trial + 1
        lblTrial.Caption = "Trial: " & trial + 1

        'If money = "" Then
        '    lblAccountVal.Caption = FormatCurrency(0)
        'Else
            lblAccountVal.Caption = FormatCurrency(money + 1000)
        'End If

        cue = 0
        uncue = 0
        nontiedcue = ""
        nontiedcue_num = 0
        ini_direction = ""

        Hint.Show
        Form1.Hide
    ElseIf trial < (total_trial - 1) Then
        lblCue1A.Caption = "?"
        lblCue1B.Caption = "?"
        lblCue2A.Caption = "?"
        lblCue2B.Caption = "?"
        lblCue3A.Caption = "?"
        lblCue3B.Caption = "?"
        lblCue4A.Caption = "?"
        lblCue4B.Caption = "?"
        lblCue5A.Caption = "?"
        lblCue5B.Caption = "?"
        lblCue6A.Caption = "?"
        lblCue6B.Caption = "?"

        lblChoiceVal.Caption = ""
        lblProbVal.Caption = ""
        lblAnswerVal.Caption = ""

        'timer related
        ElapsedTime(trial) = DateDiff("s", BeginTime(trial), Finishtime(trial))
        BeginTime(trial + 1) = Now

        Open outputfolder & "output_ex1_" & IDcode & "_" & selected & ".txt" For Append As #2
        Write #2, trial + 1, C1(trial), C2(trial), C3(trial), C4(trial), C5(trial), C6(trial), _
                  ORK(trial, 0), ORK(trial, 1), ORK(trial, 2), ORK(trial, 3), ORK(trial, 4), ORK(trial, 5), _
                  nontiedcue, nontiedcue_num, uncue, ini_direction, correct(trial), p_ans(trial), order(trial), _
                  ElapsedTime(trial), BeginTime(trial), Finishtime(trial)
        Close #2

        trial = trial + 1
        lblTrial.Caption = "Trial: " & trial + 1

        'If money = "" Then
        '    lblAccountVal.Caption = FormatCurrency(0)
        'Else
            lblAccountVal.Caption = FormatCurrency(money + 1000)
        'End If

        cue = 0
        uncue = 0
        nontiedcue = ""
        nontiedcue_num = 0
        ini_direction = ""

    Else

        'timer related
        ElapsedTime(trial) = DateDiff("s", BeginTime(trial), Finishtime(trial))

        Open outputfolder & "output_ex1_" & IDcode & "_" & selected & ".txt" For Append As #2
        Write #2, trial + 1, C1(trial), C2(trial), C3(trial), C4(trial), C5(trial), C6(trial), _
                  ORK(trial, 0), ORK(trial, 1), ORK(trial, 2), ORK(trial, 3), ORK(trial, 4), ORK(trial, 5), _
                  nontiedcue, nontiedcue_num, uncue, ini_direction, correct(trial), p_ans(trial), order(trial), _
                  ElapsedTime(trial), BeginTime(trial), Finishtime(trial), money + 1000
        Close #2
        MsgBox "You have completed all " & trial + 1 & " trials."


        Post_exp.Show
        Unload Me

    End If


End Sub
Private Sub Form_Load()
    Randomize
    Open datafile For Input As #1
    For i = 0 To 2015
        For j = 0 To 61
        Input #1, data_all(i, j)
        Next j
```

```
    Next i
    Close 1


    'choose 180 cue patterns randomly
    Dim nRandom
    Dim nCount
    Dim nCheck
    For nCount = 0 To 179
start:
    Randomize
    nRandom = Int(2016 * Rnd)
        For nCheck = 0 To 179
            If nRandom = order(nCheck) Then
            GoTo start
            End If
        Next nCheck
    order(nCount) = nRandom
    Next nCount
For t = 0 To 179
    C1A(t) = data_all(order(t), 0)
    C1B(t) = data_all(order(t), 1)
    C2A(t) = data_all(order(t), 2)
    C2B(t) = data_all(order(t), 3)
    C3A(t) = data_all(order(t), 4)
    C3B(t) = data_all(order(t), 5)
    C4A(t) = data_all(order(t), 6)
    C4B(t) = data_all(order(t), 7)
    C5A(t) = data_all(order(t), 8)
    C5B(t) = data_all(order(t), 9)
    C6A(t) = data_all(order(t), 10)
    C6B(t) = data_all(order(t), 11)
    prob(t) = data_all(order(t), 12 + selected)
Next


rank1(0) = 4
rank1(1) = 1
rank1(2) = 6
rank1(3) = 2
rank1(4) = 4
rank1(5) = 5
rank1(6) = 6
rank1(7) = 2
rank1(8) = 3
rank1(9) = 4
rank1(10) = 5
rank1(11) = 4
rank1(12) = 1
rank1(13) = 6
rank1(14) = 1
rank1(15) = 1
rank1(16) = 5
rank1(17) = 1
rank1(18) = 3
rank1(19) = 5
rank1(20) = 2
rank1(21) = 2
rank1(22) = 1
rank1(23) = 3
rank1(24) = 1
rank1(25) = 2
rank1(26) = 6
rank1(27) = 2
rank1(28) = 4
rank1(29) = 6
rank1(30) = 4
rank1(31) = 4
rank1(32) = 3
rank1(33) = 6
rank1(34) = 3
rank1(35) = 4
rank1(36) = 2
rank1(37) = 5
rank1(38) = 5
rank1(39) = 3
rank1(40) = 3
rank1(41) = 3
rank1(42) = 4
rank1(43) = 1
rank1(44) = 4
rank1(45) = 6
rank1(46) = 5
rank1(47) = 5
rank1(48) = 4
rank1(49) = 2
rank2(0) = 3
rank2(1) = 5
rank2(2) = 1
rank2(3) = 3
rank2(4) = 1
rank2(5) = 2
```

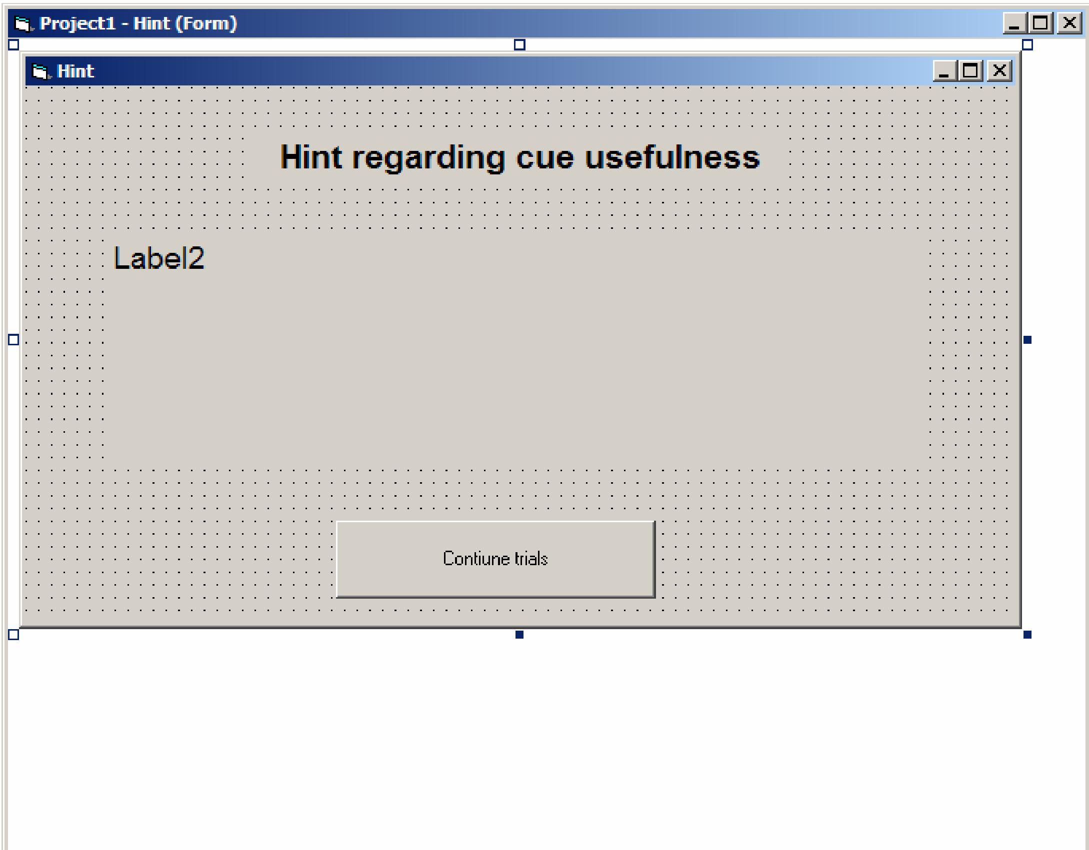
```
rank2(6) = 3
rank2(7) = 1
rank2(8) = 5
rank2(9) = 6
rank2(10) = 3
rank2(11) = 1
rank2(12) = 4
rank2(13) = 2
rank2(14) = 2
rank2(15) = 5
rank2(16) = 4
rank2(17) = 3
rank2(18) = 6
rank2(19) = 3
rank2(20) = 4
rank2(21) = 3
rank2(22) = 4
rank2(23) = 6
rank2(24) = 3
rank2(25) = 5
rank2(26) = 4
rank2(27) = 4
rank2(28) = 5
rank2(29) = 3
rank2(30) = 1
rank2(31) = 5
rank2(32) = 6
rank2(33) = 2
rank2(34) = 1
rank2(35) = 6
rank2(36) = 6
rank2(37) = 2
rank2(38) = 1
rank2(39) = 5
rank2(40) = 6
rank2(41) = 1
rank2(42) = 5
rank2(43) = 2
rank2(44) = 1
rank2(45) = 5
rank2(46) = 1
rank2(47) = 3
rank2(48) = 2
rank2(49) = 6
rank3(0) = 6
rank3(1) = 2
rank3(2) = 3
rank3(3) = 6
rank3(4) = 5
rank3(5) = 6
rank3(6) = 2
rank3(7) = 4
rank3(8) = 4
rank3(9) = 2
rank3(10) = 1
rank3(11) = 5
rank3(12) = 6
rank3(13) = 4
rank3(14) = 4
rank3(15) = 2
rank3(16) = 2
rank3(17) = 6
rank3(18) = 5
rank3(19) = 6
rank3(20) = 3
rank3(21) = 4
rank3(22) = 6
rank3(23) = 1
rank3(24) = 5
rank3(25) = 1
rank3(26) = 3
rank3(27) = 5
rank3(28) = 1
rank3(29) = 2
rank3(30) = 3
rank3(31) = 1
rank3(32) = 5
rank3(33) = 1
rank3(34) = 5
rank3(35) = 2
rank3(36) = 3
rank3(37) = 3
rank3(38) = 3
rank3(39) = 6
rank3(40) = 4
rank3(41) = 6
rank3(42) = 2
rank3(43) = 4
rank3(44) = 2
rank3(45) = 1
rank3(46) = 6
rank3(47) = 2
```

```
rank3(48) = 5
rank3(49) = 4
rank4(0) = 1
rank4(1) = 3
rank4(2) = 5
rank4(3) = 1
rank4(4) = 2
rank4(5) = 3
rank4(6) = 1
rank4(7) = 5
rank4(8) = 1
rank4(9) = 5
rank4(10) = 2
rank4(11) = 3
rank4(12) = 3
rank4(13) = 3
rank4(14) = 6
rank4(15) = 4
rank4(16) = 6
rank4(17) = 2
rank4(18) = 4
rank4(19) = 2
rank4(20) = 1
rank4(21) = 6
rank4(22) = 2
rank4(23) = 5
rank4(24) = 4
rank4(25) = 6
rank4(26) = 2
rank4(27) = 3
rank4(28) = 6
rank4(29) = 5
rank4(30) = 6
rank4(31) = 2
rank4(32) = 4
rank4(33) = 4
rank4(34) = 2
rank4(35) = 1
rank4(36) = 5
rank4(37) = 6
rank4(38) = 4
rank4(39) = 4
rank4(40) = 2
rank4(41) = 2
rank4(42) = 6
rank4(43) = 5
rank4(44) = 6
rank4(45) = 3
rank4(46) = 4
rank4(47) = 6
rank4(48) = 1
rank4(49) = 5
rank5(0) = 5
rank5(1) = 4
rank5(2) = 4
rank5(3) = 5
rank5(4) = 3
rank5(5) = 1
rank5(6) = 5
rank5(7) = 6
rank5(8) = 2
rank5(9) = 1
rank5(10) = 6
rank5(11) = 6
rank5(12) = 2
rank5(13) = 1
rank5(14) = 5
rank5(15) = 6
rank5(16) = 1
rank5(17) = 5
rank5(18) = 2
rank5(19) = 1
rank5(20) = 5
rank5(21) = 1
rank5(22) = 3
rank5(23) = 2
rank5(24) = 6
rank5(25) = 3
rank5(26) = 5
rank5(27) = 1
rank5(28) = 3
rank5(29) = 1
rank5(30) = 2
rank5(31) = 3
rank5(32) = 1
rank5(33) = 5
rank5(34) = 6
rank5(35) = 3
rank5(36) = 1
rank5(37) = 4
rank5(38) = 2
rank5(39) = 2
```

```
rank5(40) = 5
rank5(41) = 4
rank5(42) = 3
rank5(43) = 6
rank5(44) = 3
rank5(45) = 4
rank5(46) = 3
rank5(47) = 4
rank5(48) = 6
rank5(49) = 3
rank6(0) = 2
rank6(1) = 6
rank6(2) = 2
rank6(3) = 4
rank6(4) = 6
rank6(5) = 4
rank6(6) = 4
rank6(7) = 3
rank6(8) = 6
rank6(9) = 3
rank6(10) = 4
rank6(11) = 2
rank6(12) = 5
rank6(13) = 5
rank6(14) = 3
rank6(15) = 3
rank6(16) = 3
rank6(17) = 4
rank6(18) = 1
rank6(19) = 4
rank6(20) = 6
rank6(21) = 5
rank6(22) = 5
rank6(23) = 4
rank6(24) = 2
rank6(25) = 4
rank6(26) = 1
rank6(27) = 6
rank6(28) = 2
rank6(29) = 4
rank6(30) = 5
rank6(31) = 6
rank6(32) = 2
rank6(33) = 3
rank6(34) = 4
rank6(35) = 5
rank6(36) = 4
rank6(37) = 1
rank6(38) = 6
rank6(39) = 1
rank6(40) = 1
rank6(41) = 5
rank6(42) = 1
rank6(43) = 3
rank6(44) = 5
rank6(45) = 2
rank6(46) = 2
rank6(47) = 1
rank6(48) = 3
rank6(49) = 1

BeginTime(0) = Now
lblAccountVal.Caption = FormatCurrency(1000)
End Sub
```

D.1.9 Hint (hint.frm)

Form



Code

```
Private Sub Command1_Click()
Form1.Show
Unload Me
End Sub

Private Sub Form_Load()

Dim rt(5) As String

rt(0) = "Share trend"
rt(1) = "Financial reserve"
rt(2) = "Invest in new projects"
rt(3) = "An established company"
rt(4) = "Listed on SP500"
rt(5) = "Employee turnover"

'choose a cue-importance pattern randomly

Dim i As Integer

For i = 0 To 5
    If rank1(selected) = i + 1 Then rank1_text = rt(i)
    If rank2(selected) = i + 1 Then rank2_text = rt(i)
    If rank3(selected) = i + 1 Then rank3_text = rt(i)
    If rank4(selected) = i + 1 Then rank4_text = rt(i)
    If rank5(selected) = i + 1 Then rank5_text = rt(i)
    If rank6(selected) = i + 1 Then rank6_text = rt(i)
Next

all0 = """" & rank1_text & """ is the most useful piece of information followed by _
```

```
""" & rank2_text & ","" then " & """" & rank3_text & ","" then " & """" & rank4_text _
& ","" then " & """" & rank5_text & ","" then " & """" & rank6_text & "."""

lbl_rank1.Caption = all0

End Sub
```

D.1.10 Post_exp (Post_exp.frm)

Form

Code

```
Private Sub Form_Load()
    Label4.Caption = "Your identity code is " & IDcode & "."
    Label2.Caption = "Your account balance is " _
                    & FormatCurrency(money + 1000) & "."

End Sub

Private Sub Form_Unload(Cancel As Integer)

Dim oFrm As Form

For Each oFrm In Forms
    Unload oFrm
Next

End Sub
```

D.1.11 Modules

```
Public trial
Public money
Public IDcode
Public datafile
Public outputfolder
Public data_all(2015, 61)
Public cueb
Public order(179) 'index of selected cue patterns
'selected cue patterns
Public C1A(179) As String
Public C1B(179) As String
Public C2A(179) As String
Public C2B(179) As String
Public C3A(179) As String
Public C3B(179) As String
Public C4A(179) As String
Public C4B(179) As String
Public C5A(179) As String
Public C5B(179) As String
Public C6A(179) As String
Public C6B(179) As String
Public prob(179) As Single
'Public unne(179) As String
'these are for cue purchase orders
Public C1(179)
Public C2(179)
Public C3(179)
Public C4(179)
Public C5(179)
Public C6(179)
'these are for cue oline order
Public ORK(179, 5)
'for participants answers
Public p_ans(179)
'number of cues purchased
Public cue
'non-tied cue
Public nontiedcue
Public nontiedcue_num
Public ini_direction  'cue direction of the first non-tied cue
'unnecessary cue
Public uncue
Public correct(179)
Public rank1(719)
Public rank2(719)
Public rank3(719)
Public rank4(719)
Public rank5(719)
Public rank6(719)
Public selected
Public total_trial  'total number of trials -- for tesing
'timer related variables
Public BeginTime(179) As Date
Public Finishtime(179) As Date
Public ElapsedTime(179) As Long
```

D.2 Treatment 1

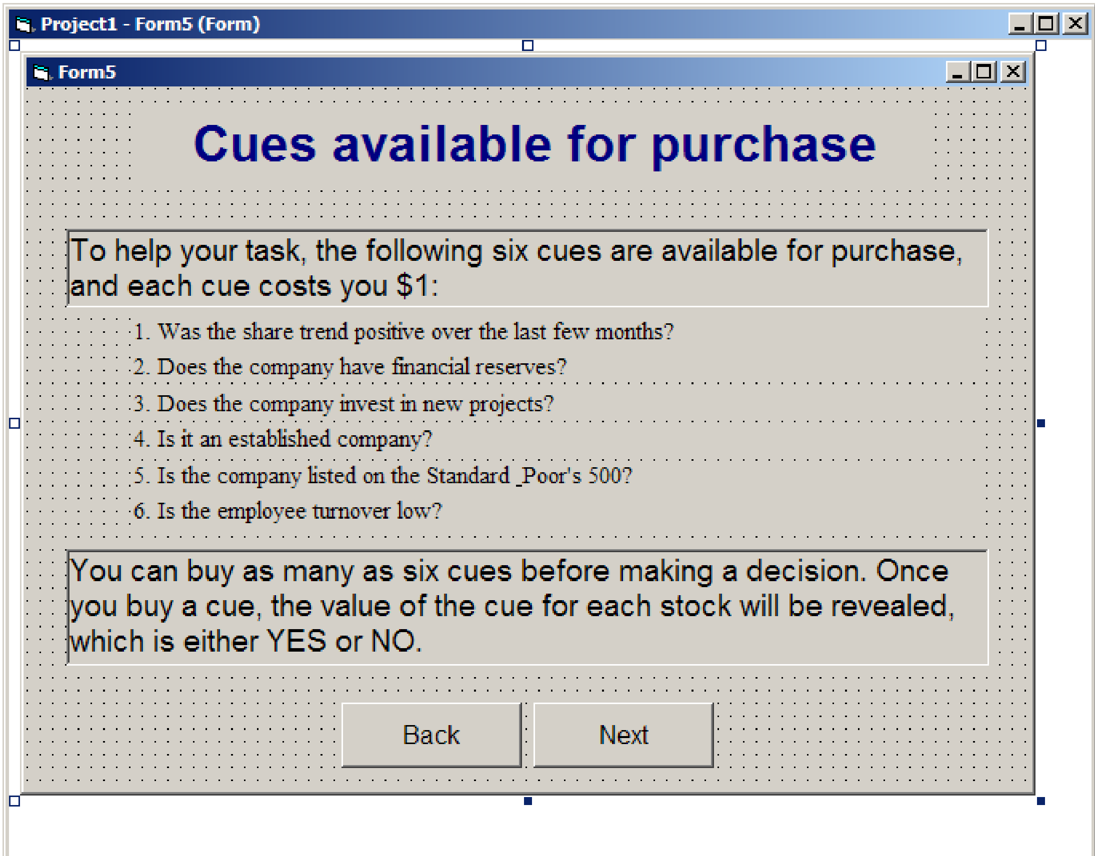
All the forms and codes are the same as those of the base case. The only difference is the data file used.

D.3 Treatment 2

Only differences between the treatment 2 case and the base case are Form5, Form7, and Form1.

D.3.1 Form5 (Inst_Cues.frm)

Form

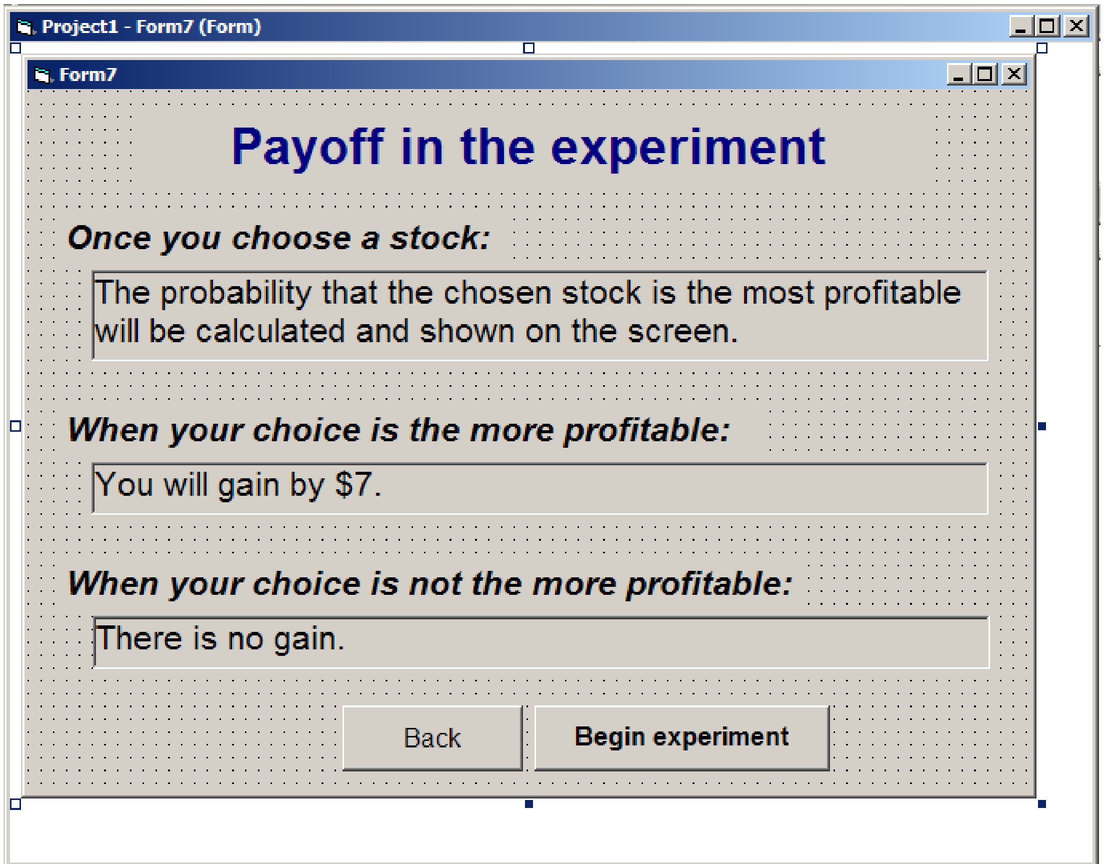


Code

```
The same as the base case
```

D.3.2 Form7 (Inst_payoff.frm)

Form



Code

```
The same as the base case
```

D.3.3 Form1 (dissertation.frm)

Form

```
The same as the base case
```

Code

```
'Buy cues and assign cue values
Private Sub cmdCue1_Click()
    If lblChoiceVal = "" And lblCue1A.Caption = "?" Then
        lblCue1A.Caption = C1A(trial)
```

```
        lblCue1B.Caption = C1B(trial)

        'online ranking
        If rank1(selected) = 1 Then
            ORK(trial, cue) = 1
        ElseIf rank2(selected) = 1 Then
            ORK(trial, cue) = 2
        ElseIf rank3(selected) = 1 Then
            ORK(trial, cue) = 3
        ElseIf rank4(selected) = 1 Then
            ORK(trial, cue) = 4
        ElseIf rank5(selected) = 1 Then
            ORK(trial, cue) = 5
        Else
            ORK(trial, cue) = 6
        End If


        cue = cue + 1
        C1(trial) = cue
        money = money - 1
        lblAccountVal.Caption = FormatCurrency(money + 1000)

        If nontiedcue <> "" Then
            uncue = uncue + 1
        End If


        If lblCue1A.Caption <> lblCue1B.Caption And nontiedcue = "" Then
            nontiedcue = 1
            nontiedcue_num = cue
            If lblCue1A.Caption = "Yes" Then
                ini_direction = "A"
            Else
                ini_direction = "B"
            End If
        End If
    End If

End Sub
Private Sub cmdCue2_Click()
    If lblChoiceVal = "" And lblCue2A.Caption = "?" Then
        lblCue2A.Caption = C2A(trial)
        lblCue2B.Caption = C2B(trial)

        'online ranking
        If rank1(selected) = 2 Then
            ORK(trial, cue) = 1
        ElseIf rank2(selected) = 2 Then
            ORK(trial, cue) = 2
        ElseIf rank3(selected) = 2 Then
            ORK(trial, cue) = 3
        ElseIf rank4(selected) = 2 Then
            ORK(trial, cue) = 4
        ElseIf rank5(selected) = 2 Then
            ORK(trial, cue) = 5
        Else
            ORK(trial, cue) = 6
        End If
        cue = cue + 1
        C2(trial) = cue
        money = money - 1
        lblAccountVal.Caption = FormatCurrency(money + 1000)


        If nontiedcue <> "" Then
            uncue = uncue + 1
        End If


        If lblCue2A.Caption <> lblCue2B.Caption And nontiedcue = "" Then
            nontiedcue = 2
            nontiedcue_num = cue
            If lblCue2A.Caption = "Yes" Then
                ini_direction = "A"
            Else
                ini_direction = "B"
            End If
        End If
    End If
End Sub
Private Sub cmdCue3_Click()
    If lblChoiceVal = "" And lblCue3A.Caption = "?" Then
        lblCue3A.Caption = C3A(trial)
        lblCue3B.Caption = C3B(trial)

        'online ranking
        If rank1(selected) = 3 Then
            ORK(trial, cue) = 1
        ElseIf rank2(selected) = 3 Then
            ORK(trial, cue) = 2
        ElseIf rank3(selected) = 3 Then
```

```
            ORK(trial, cue) = 3
        ElseIf rank4(selected) = 3 Then
            ORK(trial, cue) = 4
        ElseIf rank5(selected) = 3 Then
            ORK(trial, cue) = 5
        Else
            ORK(trial, cue) = 6
        End If
        cue = cue + 1
        C3(trial) = cue
        money = money - 1
        lblAccountVal.Caption = FormatCurrency(money + 1000)

        If nontiedcue <> "" Then
            uncue = uncue + 1
        End If

        If lblCue3A.Caption <> lblCue3B.Caption And nontiedcue = "" Then
            nontiedcue = 3
            nontiedcue_num = cue
            If lblCue3A.Caption = "Yes" Then
                ini_direction = "A"
            Else
                ini_direction = "B"
            End If
        End If
    End If
End Sub
Private Sub cmdCue4_Click()
    If lblChoiceVal = "" And lblCue4A.Caption = "?" Then
        lblCue4A.Caption = C4A(trial)
        lblCue4B.Caption = C4B(trial)

        'online ranking
        If rank1(selected) = 4 Then
            ORK(trial, cue) = 1
        ElseIf rank2(selected) = 4 Then
            ORK(trial, cue) = 2
        ElseIf rank3(selected) = 4 Then
            ORK(trial, cue) = 3
        ElseIf rank4(selected) = 4 Then
            ORK(trial, cue) = 4
        ElseIf rank5(selected) = 4 Then
            ORK(trial, cue) = 5
        Else
            ORK(trial, cue) = 6
        End If
        cue = cue + 1
        C4(trial) = cue
        money = money - 1
        lblAccountVal.Caption = FormatCurrency(money + 1000)

        If nontiedcue <> "" Then
            uncue = uncue + 1
        End If

        If lblCue4A.Caption <> lblCue4B.Caption And nontiedcue = "" Then
            nontiedcue = 4
            nontiedcue_num = cue
            If lblCue4A.Caption = "Yes" Then
                ini_direction = "A"
            Else
                ini_direction = "B"
            End If
        End If
    End If
End Sub
Private Sub cmdCue5_Click()
    If lblChoiceVal = "" And lblCue5A.Caption = "?" Then
        lblCue5A.Caption = C5A(trial)
        lblCue5B.Caption = C5B(trial)

        'online ranking
        If rank1(selected) = 5 Then
            ORK(trial, cue) = 1
        ElseIf rank2(selected) = 5 Then
            ORK(trial, cue) = 2
        ElseIf rank3(selected) = 5 Then
            ORK(trial, cue) = 3
        ElseIf rank4(selected) = 5 Then
            ORK(trial, cue) = 4
        ElseIf rank5(selected) = 5 Then
            ORK(trial, cue) = 5
        Else
            ORK(trial, cue) = 6
        End If

        cue = cue + 1
        C5(trial) = cue
        money = money - 1
        lblAccountVal.Caption = FormatCurrency(money + 1000)
```

```
        If nontiedcue <> "" Then
            uncue = uncue + 1
        End If


        If lblCue5A.Caption <> lblCue5B.Caption And nontiedcue = "" Then
            nontiedcue = 5
            nontiedcue_num = cue
            If lblCue5A.Caption = "Yes" Then
                ini_direction = "A"
            Else
                ini_direction = "B"
            End If
        End If
    End If
End Sub
Private Sub cmdCue6_Click()
    If lblChoiceVal = "" And lblCue6A.Caption = "?" Then
        lblCue6A.Caption = C6A(trial)
        lblCue6B.Caption = C6B(trial)

        'online ranking
        If rank1(selected) = 6 Then
            ORK(trial, cue) = 1
        ElseIf rank2(selected) = 6 Then
            ORK(trial, cue) = 2
        ElseIf rank3(selected) = 6 Then
            ORK(trial, cue) = 3
        ElseIf rank4(selected) = 6 Then
            ORK(trial, cue) = 4
        ElseIf rank5(selected) = 6 Then
            ORK(trial, cue) = 5
        Else
            ORK(trial, cue) = 6
        End If

        cue = cue + 1
        C6(trial) = cue
        money = money - 1
        lblAccountVal.Caption = FormatCurrency(money + 1000)

        If nontiedcue <> "" Then
            uncue = uncue + 1
        End If

        If lblCue6A.Caption <> lblCue6B.Caption And nontiedcue = "" Then
            nontiedcue = 6
            nontiedcue_num = cue
            If lblCue6A.Caption = "Yes" Then
                ini_direction = "A"
            Else
                ini_direction = "B"
            End If
        End If
    End If
End Sub
'When choose A or B, assign the chosen share in Your Choice
Private Sub cmdStockA_Click()
    If lblChoiceVal.Caption = "" Then
        'answer = MsgBox("Your choice is stock A.", vbQuestion + vbYesNo, "Confirm your choice")
        'If answer = vbYes Then
            lblChoiceVal.Caption = "A"
            lblProbVal.Caption = FormatNumber(prob(trial), 4)
            p_ans(trial) = "A"
            ' Put more stuff here
        'Else
         '   txtChoice.Text = ""

        'timer related
        Finishtime(trial) = Now

        'Random number generator decide which cue is the more profitable one
        If Rnd < prob(trial) Then
            lblAnswerVal.Caption = "A"
        Else
            lblAnswerVal.Caption = "B"
        End If

        'determine prize money
        If lblAnswerVal.Caption = "A" Then
            money = money + 7
            lblAccountVal.Caption = FormatCurrency(money + 1000)
            ' 1 = correct and 0 = wrong
            correct(trial) = 1
        Else

            lblAccountVal.Caption = FormatCurrency(money + 1000)
            correct(trial) = 0
        End If

    Else
        MsgBox ("You have already made a choice!")
```

```
    End If
End Sub
Private Sub cmdStockB_Click()
    If lblChoiceVal.Caption = "" Then
        'answer = MsgBox("Your choice is stock A.", vbQuestion + vbYesNo, "Confirm your choice")
        'If answer = vbYes Then
            lblChoiceVal.Caption = "B"
            lblProbVal.Caption = FormatNumber(1 - prob(trial), 4)
            p_ans(trial) = "B"
            ' Put more stuff here
        'Else
         '   txtChoice.Text = ""

        Finishtime(trial) = Now

        'Random number generator decide which cue is the more profitable one

        If Rnd < 1 - prob(trial) Then
            lblAnswerVal.Caption = "B"
        Else
            lblAnswerVal.Caption = "A"
        End If


        If lblAnswerVal.Caption = "B" Then
            money = money + 7
            lblAccountVal.Caption = FormatCurrency(money + 1000)
            ' 1 = correct and 0 = wrong
            correct(trial) = 1
        Else
            lblAccountVal.Caption = FormatCurrency(money + 1000)
            correct(trial) = 0
        End If

    Else
        MsgBox ("You have already made a choice!")
    End If
End Sub
Private Sub cmdNext_Click()
    If lblChoiceVal.Caption = "" Then
        MsgBox ("Please select a stock.")
    ElseIf trial < (total_trial / 3 - 1) Then
        '180 trials
        'reset the cue values to ?
        lblCue1A.Caption = "?"
        lblCue1B.Caption = "?"
        lblCue2A.Caption = "?"
        lblCue2B.Caption = "?"
        lblCue3A.Caption = "?"
        lblCue3B.Caption = "?"
        lblCue4A.Caption = "?"
        lblCue4B.Caption = "?"
        lblCue5A.Caption = "?"
        lblCue5B.Caption = "?"
        lblCue6A.Caption = "?"
        lblCue6B.Caption = "?"

        lblChoiceVal.Caption = ""
        lblProbVal.Caption = ""
        lblAnswerVal.Caption = ""

        'timer related
        ElapsedTime(trial) = DateDiff("s", BeginTime(trial), Finishtime(trial))
        BeginTime(trial + 1) = Now


        Open outputfolder & "output_ex3_" & IDcode & "_" & selected & ".txt" For Append As #2
        Write #2, trial + 1, C1(trial), C2(trial), C3(trial), C4(trial), C5(trial), C6(trial), _
                  ORK(trial, 0), ORK(trial, 1), ORK(trial, 2), ORK(trial, 3), ORK(trial, 4), ORK(trial, 5), _
                  nontiedcue, nontiedcue_num, uncue, ini_direction, correct(trial), p_ans(trial), order(trial), _
                  ElapsedTime(trial), BeginTime(trial), Finishtime(trial)
        Close #2
        trial = trial + 1
        lblTrial.Caption = "Trial: " & trial + 1



        'If money = "" Then
        '    lblAccountVal.Caption = FormatCurrency(0)
        'Else
            lblAccountVal.Caption = FormatCurrency(money + 1000)
        'End If

        cue = 0
        uncue = 0
        nontiedcue = ""
        nontiedcue_num = 0
        ini_direction = ""

    ElseIf trial = (total_trial / 3 - 1) Then

        lblCue1A.Caption = "?"
```

```
    lblCue1B.Caption = "?"
    lblCue2A.Caption = "?"
    lblCue2B.Caption = "?"
    lblCue3A.Caption = "?"
    lblCue3B.Caption = "?"
    lblCue4A.Caption = "?"
    lblCue4B.Caption = "?"
    lblCue5A.Caption = "?"
    lblCue5B.Caption = "?"
    lblCue6A.Caption = "?"
    lblCue6B.Caption = "?"

    lblChoiceVal.Caption = ""
    lblProbVal.Caption = ""
    lblAnswerVal.Caption = ""

    'timer related
    ElapsedTime(trial) = DateDiff("s", BeginTime(trial), Finishtime(trial))
    BeginTime(trial + 1) = Now


    Open outputfolder & "output_ex3_" & IDcode & "_" & selected & ".txt" For Append As #2
    Write #2, trial + 1, C1(trial), C2(trial), C3(trial), C4(trial), C5(trial), C6(trial), _
              ORK(trial, 0), ORK(trial, 1), ORK(trial, 2), ORK(trial, 3), ORK(trial, 4), ORK(trial, 5), _
              nontiedcue, nontiedcue_num, uncue, ini_direction, correct(trial), p_ans(trial), order(trial), _
              ElapsedTime(trial), BeginTime(trial), Finishtime(trial)
    Close #2


    trial = trial + 1
    lblTrial.Caption = "Trial: " & trial + 1

    'If money = "" Then
    '    lblAccountVal.Caption = FormatCurrency(0)
    'Else
        lblAccountVal.Caption = FormatCurrency(money + 1000)
    'End If

    cue = 0
    uncue = 0
    nontiedcue = ""
    nontiedcue_num = 0
    ini_direction = ""

    Hint.Show
    Form1.Hide

ElseIf trial < (2 * total_trial / 3 - 1) Then
    '180 trials
    'reset the cue values to ?
    lblCue1A.Caption = "?"
    lblCue1B.Caption = "?"
    lblCue2A.Caption = "?"
    lblCue2B.Caption = "?"
    lblCue3A.Caption = "?"
    lblCue3B.Caption = "?"
    lblCue4A.Caption = "?"
    lblCue4B.Caption = "?"
    lblCue5A.Caption = "?"
    lblCue5B.Caption = "?"
    lblCue6A.Caption = "?"
    lblCue6B.Caption = "?"

    lblChoiceVal.Caption = ""
    lblProbVal.Caption = ""
    lblAnswerVal.Caption = ""

    'timer related
    ElapsedTime(trial) = DateDiff("s", BeginTime(trial), Finishtime(trial))
    BeginTime(trial + 1) = Now


    Open outputfolder & "output_ex3_" & IDcode & "_" & selected & ".txt" For Append As #2
    Write #2, trial + 1, C1(trial), C2(trial), C3(trial), C4(trial), C5(trial), C6(trial), _
              ORK(trial, 0), ORK(trial, 1), ORK(trial, 2), ORK(trial, 3), ORK(trial, 4), ORK(trial, 5), _
              nontiedcue, nontiedcue_num, uncue, ini_direction, correct(trial), p_ans(trial), order(trial), _
              ElapsedTime(trial), BeginTime(trial), Finishtime(trial)
    Close #2

    trial = trial + 1
    lblTrial.Caption = "Trial: " & trial + 1

    'If money = "" Then
    '    lblAccountVal.Caption = FormatCurrency(0)
    'Else
        lblAccountVal.Caption = FormatCurrency(money + 1000)
    'End If

    cue = 0
    uncue = 0
    nontiedcue = ""
    nontiedcue_num = 0
```

```
    ini_direction = ""

ElseIf trial = (2 * total_trial / 3 - 1) Then
    lblCue1A.Caption = "?"
    lblCue1B.Caption = "?"
    lblCue2A.Caption = "?"
    lblCue2B.Caption = "?"
    lblCue3A.Caption = "?"
    lblCue3B.Caption = "?"
    lblCue4A.Caption = "?"
    lblCue4B.Caption = "?"
    lblCue5A.Caption = "?"
    lblCue5B.Caption = "?"
    lblCue6A.Caption = "?"
    lblCue6B.Caption = "?"

    lblChoiceVal.Caption = ""
    lblProbVal.Caption = ""
    lblAnswerVal.Caption = ""

    'timer related
    ElapsedTime(trial) = DateDiff("s", BeginTime(trial), Finishtime(trial))
    BeginTime(trial + 1) = Now


    Open outputfolder & "output_ex3_" & IDcode & "_" & selected & ".txt" For Append As #2
    Write #2, trial + 1, C1(trial), C2(trial), C3(trial), C4(trial), C5(trial), C6(trial), _
              ORK(trial, 0), ORK(trial, 1), ORK(trial, 2), ORK(trial, 3), ORK(trial, 4), ORK(trial, 5), _
              nontiedcue, nontiedcue_num, uncue, ini_direction, correct(trial), p_ans(trial), order(trial), _
              ElapsedTime(trial), BeginTime(trial), Finishtime(trial)
    Close #2


    trial = trial + 1
    lblTrial.Caption = "Trial: " & trial + 1

    'If money = "" Then
    '    lblAccountVal.Caption = FormatCurrency(0)
    'Else
        lblAccountVal.Caption = FormatCurrency(money + 1000)
    'End If

    cue = 0
    uncue = 0
    nontiedcue = ""
    nontiedcue_num = 0
    ini_direction = ""

    Hint.Show
    Form1.Hide
ElseIf trial < (total_trial - 1) Then
    lblCue1A.Caption = "?"
    lblCue1B.Caption = "?"
    lblCue2A.Caption = "?"
    lblCue2B.Caption = "?"
    lblCue3A.Caption = "?"
    lblCue3B.Caption = "?"
    lblCue4A.Caption = "?"
    lblCue4B.Caption = "?"
    lblCue5A.Caption = "?"
    lblCue5B.Caption = "?"
    lblCue6A.Caption = "?"
    lblCue6B.Caption = "?"

    lblChoiceVal.Caption = ""
    lblProbVal.Caption = ""
    lblAnswerVal.Caption = ""

    'timer related
    ElapsedTime(trial) = DateDiff("s", BeginTime(trial), Finishtime(trial))
    BeginTime(trial + 1) = Now


    Open outputfolder & "output_ex3_" & IDcode & "_" & selected & ".txt" For Append As #2
    Write #2, trial + 1, C1(trial), C2(trial), C3(trial), C4(trial), C5(trial), C6(trial), _
              ORK(trial, 0), ORK(trial, 1), ORK(trial, 2), ORK(trial, 3), ORK(trial, 4), ORK(trial, 5), _
              nontiedcue, nontiedcue_num, uncue, ini_direction, correct(trial), p_ans(trial), order(trial), _
              ElapsedTime(trial), BeginTime(trial), Finishtime(trial)
    Close #2

    trial = trial + 1
    lblTrial.Caption = "Trial: " & trial + 1

    'If money = "" Then
    '    lblAccountVal.Caption = FormatCurrency(0)
    'Else
        lblAccountVal.Caption = FormatCurrency(money + 1000)
    'End If

    cue = 0
    uncue = 0
    nontiedcue = ""
```

```
        nontiedcue_num = 0
        ini_direction = ""

    Else

        'Open "c:\output.txt" For Output As #2
        'For i = 0 To 179
        '    Write #2, i + 1, C1(i), C2(i), C3(i), C4(i), C5(i), C6(i), correct(i), p_ans(i)
        'Next
        'Close #2

        'timer related
        ElapsedTime(trial) = DateDiff("s", BeginTime(trial), Finishtime(trial))

        Open outputfolder & "output_ex3_" & IDcode & "_" & selected & ".txt" For Append As #2
        Write #2, trial + 1, C1(trial), C2(trial), C3(trial), C4(trial), C5(trial), C6(trial), _
                  ORK(trial, 0), ORK(trial, 1), ORK(trial, 2), ORK(trial, 3), ORK(trial, 4), ORK(trial, 5), _
                  nontiedcue, nontiedcue_num, uncue, ini_direction, correct(trial), p_ans(trial), order(trial), _
                  ElapsedTime(trial), BeginTime(trial), Finishtime(trial), money + 1000

        Close #2
        MsgBox "You have completed all " & trial + 1 & " trials."


        Post_exp.Show
        Unload Me

    End If

    'Text1.Text = order(trial)

End Sub
Private Sub Form_Load()
    Randomize
    Open datafile For Input As #1
    For i = 0 To 2015
        For j = 0 To 61
        Input #1, data_all(i, j)
        Next j
    Next i
    Close 1


    'choose 180 cue patterns randomly
    Dim nRandom
    Dim nCount
    Dim nCheck
    For nCount = 0 To 179
start:
    Randomize
    nRandom = Int(2016 * Rnd)
        For nCheck = 0 To 179
            If nRandom = order(nCheck) Then
            GoTo start
            End If
        Next nCheck
    order(nCount) = nRandom
    Next nCount
For t = 0 To 179
    C1A(t) = data_all(order(t), 0)
    C1B(t) = data_all(order(t), 1)
    C2A(t) = data_all(order(t), 2)
    C2B(t) = data_all(order(t), 3)
    C3A(t) = data_all(order(t), 4)
    C3B(t) = data_all(order(t), 5)
    C4A(t) = data_all(order(t), 6)
    C4B(t) = data_all(order(t), 7)
    C5A(t) = data_all(order(t), 8)
    C5B(t) = data_all(order(t), 9)
    C6A(t) = data_all(order(t), 10)
    C6B(t) = data_all(order(t), 11)
    prob(t) = data_all(order(t), 12 + selected)
Next

    'to decide random order for cue importance
    'Open "c:\order.txt" For Input As #3
    'For i = 0 To 49
    '    Input #3, rank1(i), rank2(i), rank3(i), rank4(i), rank5(i), rank6(i)
    'Next
    'Close 3

rank1(0) = 4
rank1(1) = 1
rank1(2) = 6
rank1(3) = 2
rank1(4) = 4
rank1(5) = 5
rank1(6) = 6
rank1(7) = 2
rank1(8) = 3
rank1(9) = 4
rank1(10) = 5
```

```
rank1(11) = 4
rank1(12) = 1
rank1(13) = 6
rank1(14) = 1
rank1(15) = 1
rank1(16) = 5
rank1(17) = 1
rank1(18) = 3
rank1(19) = 5
rank1(20) = 2
rank1(21) = 2
rank1(22) = 1
rank1(23) = 3
rank1(24) = 1
rank1(25) = 2
rank1(26) = 6
rank1(27) = 2
rank1(28) = 4
rank1(29) = 6
rank1(30) = 4
rank1(31) = 4
rank1(32) = 3
rank1(33) = 6
rank1(34) = 3
rank1(35) = 4
rank1(36) = 2
rank1(37) = 5
rank1(38) = 5
rank1(39) = 3
rank1(40) = 3
rank1(41) = 3
rank1(42) = 4
rank1(43) = 1
rank1(44) = 4
rank1(45) = 6
rank1(46) = 5
rank1(47) = 5
rank1(48) = 4
rank1(49) = 2
rank2(0) = 3
rank2(1) = 5
rank2(2) = 1
rank2(3) = 3
rank2(4) = 1
rank2(5) = 2
rank2(6) = 3
rank2(7) = 1
rank2(8) = 5
rank2(9) = 6
rank2(10) = 3
rank2(11) = 1
rank2(12) = 4
rank2(13) = 2
rank2(14) = 2
rank2(15) = 5
rank2(16) = 4
rank2(17) = 3
rank2(18) = 6
rank2(19) = 3
rank2(20) = 4
rank2(21) = 3
rank2(22) = 4
rank2(23) = 6
rank2(24) = 3
rank2(25) = 5
rank2(26) = 4
rank2(27) = 4
rank2(28) = 5
rank2(29) = 3
rank2(30) = 1
rank2(31) = 5
rank2(32) = 6
rank2(33) = 2
rank2(34) = 1
rank2(35) = 6
rank2(36) = 6
rank2(37) = 2
rank2(38) = 1
rank2(39) = 5
rank2(40) = 6
rank2(41) = 1
rank2(42) = 5
rank2(43) = 2
rank2(44) = 1
rank2(45) = 5
rank2(46) = 1
rank2(47) = 3
rank2(48) = 2
rank2(49) = 6
rank3(0) = 6
rank3(1) = 2
rank3(2) = 3
```

```
rank3(3) = 6
rank3(4) = 5
rank3(5) = 6
rank3(6) = 2
rank3(7) = 4
rank3(8) = 4
rank3(9) = 2
rank3(10) = 1
rank3(11) = 5
rank3(12) = 6
rank3(13) = 4
rank3(14) = 4
rank3(15) = 2
rank3(16) = 2
rank3(17) = 6
rank3(18) = 5
rank3(19) = 6
rank3(20) = 3
rank3(21) = 4
rank3(22) = 6
rank3(23) = 1
rank3(24) = 5
rank3(25) = 1
rank3(26) = 3
rank3(27) = 5
rank3(28) = 1
rank3(29) = 2
rank3(30) = 3
rank3(31) = 1
rank3(32) = 5
rank3(33) = 1
rank3(34) = 5
rank3(35) = 2
rank3(36) = 3
rank3(37) = 3
rank3(38) = 3
rank3(39) = 6
rank3(40) = 4
rank3(41) = 6
rank3(42) = 2
rank3(43) = 4
rank3(44) = 2
rank3(45) = 1
rank3(46) = 6
rank3(47) = 2
rank3(48) = 5
rank3(49) = 4
rank4(0) = 1
rank4(1) = 3
rank4(2) = 5
rank4(3) = 1
rank4(4) = 2
rank4(5) = 3
rank4(6) = 1
rank4(7) = 5
rank4(8) = 1
rank4(9) = 5
rank4(10) = 2
rank4(11) = 3
rank4(12) = 3
rank4(13) = 3
rank4(14) = 6
rank4(15) = 4
rank4(16) = 6
rank4(17) = 2
rank4(18) = 4
rank4(19) = 2
rank4(20) = 1
rank4(21) = 6
rank4(22) = 2
rank4(23) = 5
rank4(24) = 4
rank4(25) = 6
rank4(26) = 2
rank4(27) = 3
rank4(28) = 6
rank4(29) = 5
rank4(30) = 6
rank4(31) = 2
rank4(32) = 4
rank4(33) = 4
rank4(34) = 2
rank4(35) = 1
rank4(36) = 5
rank4(37) = 6
rank4(38) = 4
rank4(39) = 4
rank4(40) = 2
rank4(41) = 2
rank4(42) = 6
rank4(43) = 5
rank4(44) = 6
```

```
rank4(45) = 3
rank4(46) = 4
rank4(47) = 6
rank4(48) = 1
rank4(49) = 5
rank5(0) = 5
rank5(1) = 4
rank5(2) = 4
rank5(3) = 5
rank5(4) = 3
rank5(5) = 1
rank5(6) = 5
rank5(7) = 6
rank5(8) = 2
rank5(9) = 1
rank5(10) = 6
rank5(11) = 6
rank5(12) = 2
rank5(13) = 1
rank5(14) = 5
rank5(15) = 6
rank5(16) = 1
rank5(17) = 5
rank5(18) = 2
rank5(19) = 1
rank5(20) = 5
rank5(21) = 1
rank5(22) = 3
rank5(23) = 2
rank5(24) = 6
rank5(25) = 3
rank5(26) = 5
rank5(27) = 1
rank5(28) = 3
rank5(29) = 1
rank5(30) = 2
rank5(31) = 3
rank5(32) = 1
rank5(33) = 5
rank5(34) = 6
rank5(35) = 3
rank5(36) = 1
rank5(37) = 4
rank5(38) = 2
rank5(39) = 2
rank5(40) = 5
rank5(41) = 4
rank5(42) = 3
rank5(43) = 6
rank5(44) = 3
rank5(45) = 4
rank5(46) = 3
rank5(47) = 4
rank5(48) = 6
rank5(49) = 3
rank6(0) = 2
rank6(1) = 6
rank6(2) = 2
rank6(3) = 4
rank6(4) = 6
rank6(5) = 4
rank6(6) = 4
rank6(7) = 3
rank6(8) = 6
rank6(9) = 3
rank6(10) = 4
rank6(11) = 2
rank6(12) = 5
rank6(13) = 5
rank6(14) = 3
rank6(15) = 3
rank6(16) = 3
rank6(17) = 4
rank6(18) = 1
rank6(19) = 4
rank6(20) = 6
rank6(21) = 5
rank6(22) = 5
rank6(23) = 4
rank6(24) = 2
rank6(25) = 4
rank6(26) = 1
rank6(27) = 6
rank6(28) = 2
rank6(29) = 4
rank6(30) = 5
rank6(31) = 6
rank6(32) = 2
rank6(33) = 3
rank6(34) = 4
rank6(35) = 5
rank6(36) = 4
```

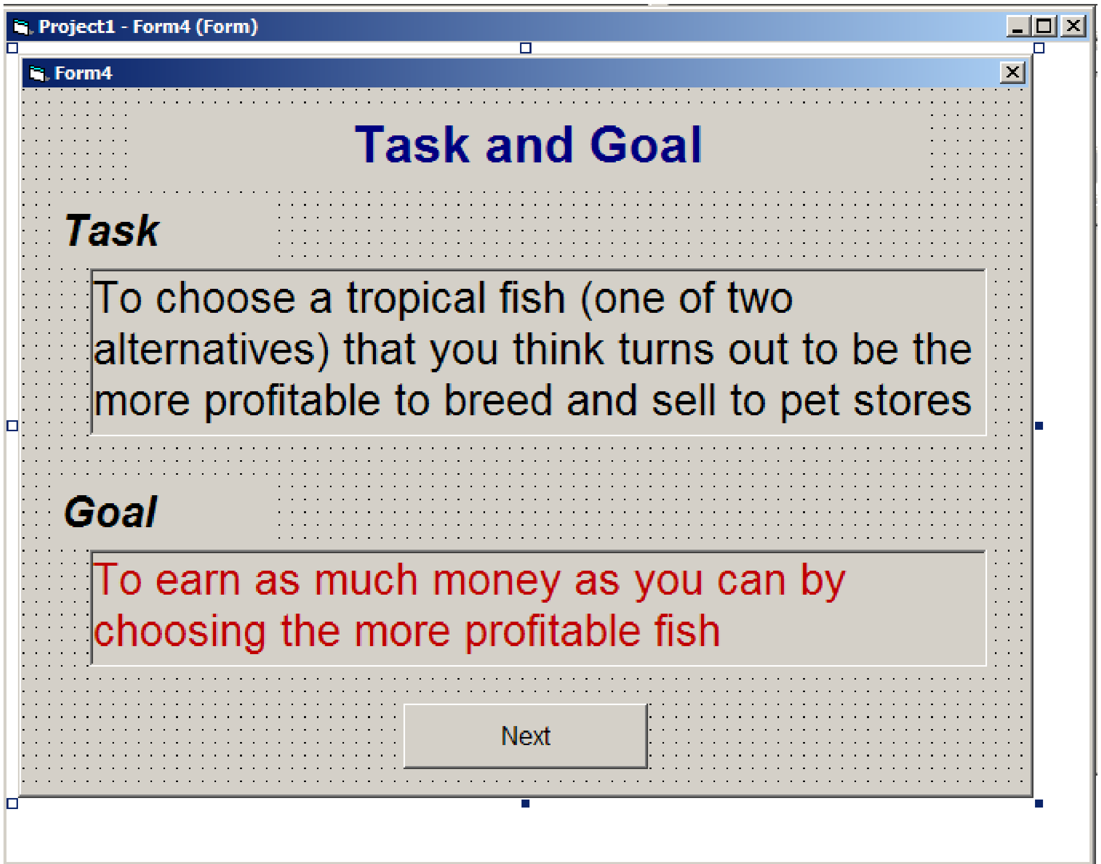
```
rank6(37) = 1
rank6(38) = 6
rank6(39) = 1
rank6(40) = 1
rank6(41) = 5
rank6(42) = 1
rank6(43) = 3
rank6(44) = 5
rank6(45) = 2
rank6(46) = 2
rank6(47) = 1
rank6(48) = 3
rank6(49) = 1

BeginTime(0) = Now
lblAccountVal.Caption = FormatCurrency(1000)
End Sub
```

D.4 Treatment 3

Only differences between the treatment 2 case and the base case are Form4, Form5, Form7, and Hint.

D.4.1 Form4 (Inst_goal.frm)

Form

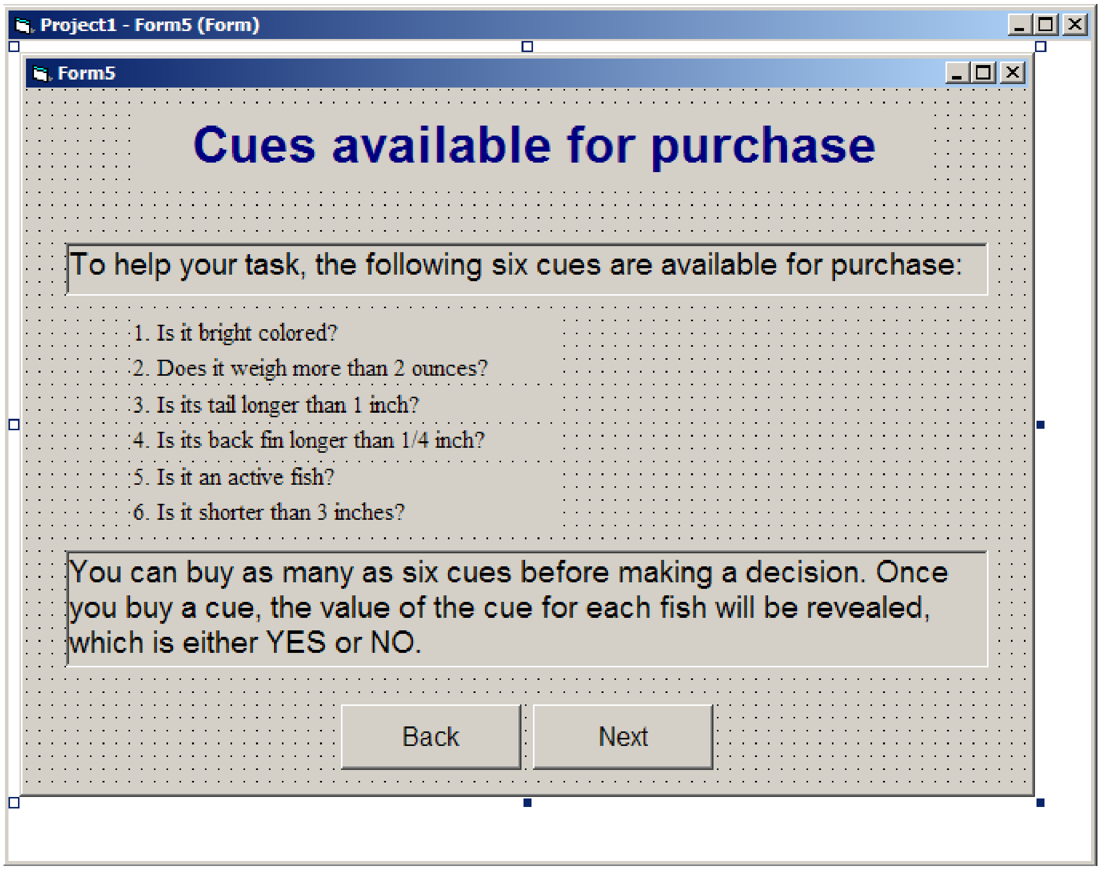


Code

```
The same as the base case
```

D.4.2 Form5 (Inst_Cues.frm)

Form

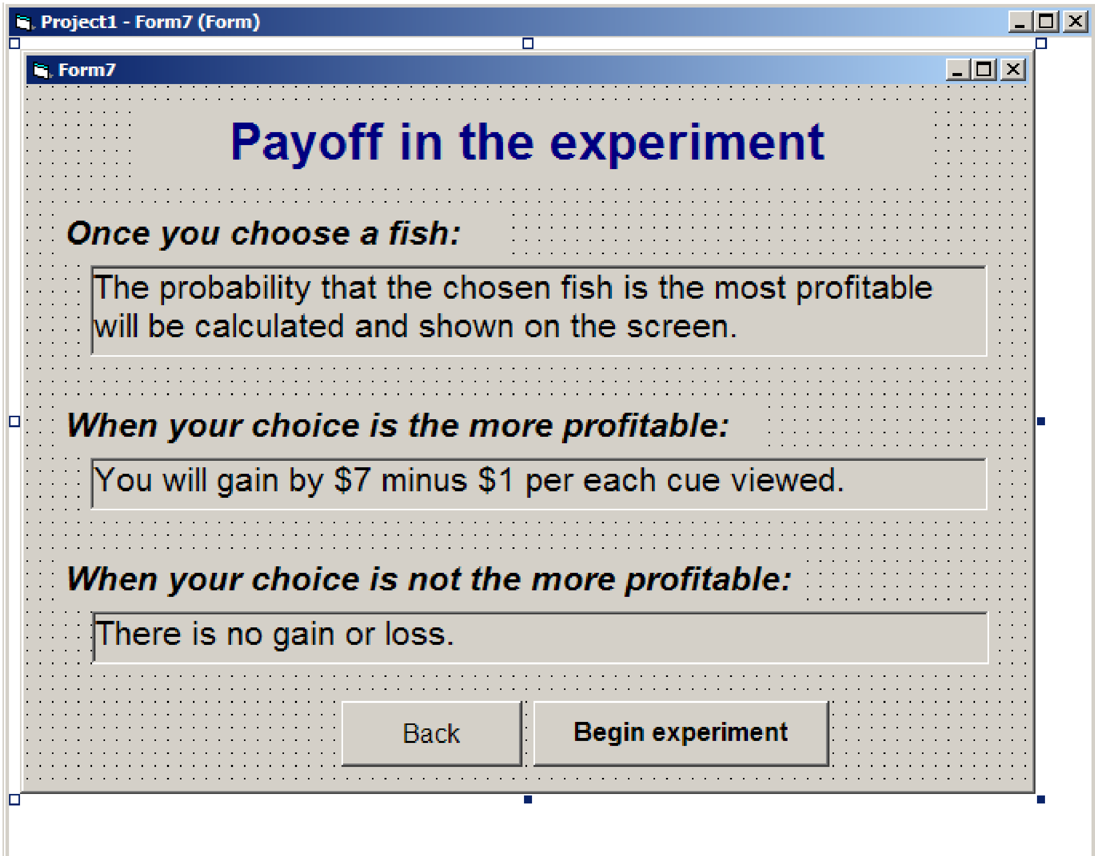


Code

```
The same as the base case
```

D.4.3 Form7 (Inst_payoff.frm)

Form



Code

```
The same as the base case
```

D.4.4 Hint (hint.frm)

Form

```
The same as the base case
```

Code

```
Private Sub Command1_Click()
Form1.Show
Unload Me
End Sub
```

```
Private Sub Form_Load()
Dim rt(5) As String
rt(0) = "Bright colored"
rt(1) = "Weight"
rt(2) = "Length of a tail fin"
rt(3) = "Length of a back fin"
rt(4) = "Active fish"
rt(5) = "Length of a fish"
'choose a cue-importance pattern randomly
Dim i As Integer
For i = 0 To 5
    If rank1(selected) = i + 1 Then rank1_text = rt(i)
    If rank2(selected) = i + 1 Then rank2_text = rt(i)
    If rank3(selected) = i + 1 Then rank3_text = rt(i)
    If rank4(selected) = i + 1 Then rank4_text = rt(i)
    If rank5(selected) = i + 1 Then rank5_text = rt(i)
    If rank6(selected) = i + 1 Then rank6_text = rt(i)
Next
all0 = """" & rank1_text & """ is the most useful piece of information followed by _

""" & rank2_text & ","" then " & """" & rank3_text & ","" then " & """" & rank4_text & _

","" then " & """" & rank5_text & ","" then " & """" & rank6_text & "."""

lbl_rank1.Caption = all0
End Sub
```

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