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Testing the Modigliani-Miller theorem directly in the lab

M. Vittoria Levati* Jianying Qiu† Prashanth Mahagaonkar‡

Abstract

We present an experiment designed to test the Modigliani-Miller theorem. Applying a general equilibrium approach and not allowing for arbitrage among firms with different capital structures, we find that, in accordance with the theorem, participants well recognize changes in the systematic risk of equity associated with increasing leverage and, accordingly, demand higher rate of return. Yet, this adjustment is not perfect: subjects underestimate the systematic risk of low-leveraged equity whereas they overestimate the systematic risk of high-leveraged equity, resulting in a U-shaped cost of capital. A (control) individual decision-making experiment, eliciting several points on individual demand and supply curves for shares, provides some support for the theorem.

Keywords Modigliani-Miller theorem, Experiments, Decision making under risk, General equilibrium

JEL Classification G32, C91, G12, D53

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1 Introduction

Modigliani and Miller (1958) demonstrate that in a perfect capital market[1] the value of a firm is independent of how that firm is financed. Since its appearance this theorem (now known as the Modigliani-Miller or MM theorem) has been an object of lively debates and extensive empirical analyses. The original article itself includes a section devoted to testing the propositions on oil and electricity utility industries. The results show that there is little evidence of a relationship between leverage and the cost of capital. In a follow-up study, Miller and Modigliani (1966) adopt a two-stage instrumental variable procedure to estimate the cost of capital for a sample of large US electric utilities for the years 1954, 1956, and 1957. They find no evidence for "sizable leverage or dividend effects of the kind assumed in much of the traditional literature of finance".

The opposition to the MM theorem comes from many angles. Weston (1963) tests the theorem using the same sample of electricity utility industries as used by Modigliani and Miller (1958), but for the year 1959 rather than for the years 1947 and 1948. His multiple regression analysis indicates that leverage does have an influence on a firm's cost of capital when earnings growth is taken into account. Robichek et al. (1967) extend the analysis of Miller and Modigliani (1966) to the years 1955 and 1958–64. They conclude that MM's results are a consequence of circumstances prevailing at the time of their study. Davenport (1971) uses data on three industry groups (chemicals, food, and metal manufacturing), and his results are indicative of a U-shaped cost of capital with respect to leverage. Other empirical studies suggesting that a firm's value changes significantly in response to changes in the capital structure include Masulis (1980), Dann (1981), Masulis and Korwar (1986), Pinegar and Lease (1986), Graham and Harvey (2001), and Arzac and Glosten (2005). These studies and, generally, most of the works rejecting the MM theorem rely on some kind of market imperfections. However, no study so far has tried to focus on the more fundamental question: could the violation of the MM theorem be inherent in the valuation process?

A clean and conclusive test of the above fundamental question using real market data is virtually impossible. Not only the restrictions and assumptions that the theorem demands may not be fulfilled in the real world, but also the *ceteris paribus* conditions, necessary to explore the impact of the debt-equity ratio on the firm's value in isolation, are often violated. Hence, an apparent significant correlation between leverage and cost of capital may be accounted for by the presence of imperfections such as taxes or transactions costs.

[1] That is, a market where there are no taxes, transactions costs, or asymmetric information, and investors and firms are price takers.

By the same token, the seemingly independence of the capital structure from the leverage ratio may be due to a relationship between leverage and other factors influencing the cost of capital, e.g., earnings growth may offset the effect of leverage on the cost of capital (see e.g. Weston, 1963). Myers (2001, p. 86) rightly admits that the MM theorem "is exceptionally difficult to test directly". Unambiguous experimental evidence of the theorem seems therefore much-needed before we can be confident about the impact of the capital structure on the firm's value.

Motivated by these considerations, in this paper we test the MM theorem directly in a competitive market experiment. Creating a laboratory environment as close as possible to the theoretical model, we want to assess whether subjects' valuations of firms that generate the same income stream vary with the capital structure. The model we use is adapted from that of Stiglitz (1969). Using a general equilibrium approach, we prove rigorously that if individuals can borrow at the same market rate of interest as firms and there is no bankruptcy, the MM theorem always holds in equilibrium, and this result does not depend on individuals' risk attitudes and initial wealth positions. To test a key assumption of our model, we also run a (control) individual decision-making experiment.

Details about the MM theorem and our adaptation of Stiglitz's (1969) model are presented in Section 2, after discussing the U-shaped cost of capital approach. The experimental design is laid out in Section 3. The results are reported in Section 4. Section 5 concludes.

2 Theories of the cost of capital

Before 1958 the cost of capital was thought to possess a U shape. The argument runs as follows. Since equity is more risky (and thus more costly) than debt,[2] a firm can reduce its cost of capital by issuing debt in exchange for equity. As the debt-equity ratio of the leveraged firm increases further, default risk becomes larger and, after some point, debt becomes more expensive than equity.

To clarify the issue, consider a firm with market value of bonds B and market value of equity or shares S, so that $V \equiv B + S$ is the market value of the firm. Denote by $\tau = \frac{B}{V}$ the leverage ratio, by i the expected rate of return on equity, and by r the rate of return

[2] A firm promises to make contractual payments whatever its earnings. Thus, when there is no bankruptcy, there is no risk. When there is a positive probability of bankruptcy, debt is still the less risky option because it has priority over equity in payment.

on debts. The unit cost of capital, ρ, is simply the weighted average of i and r:

$$\begin{aligned}\rho &= \frac{S}{V}i + \frac{B}{V}r \\ &= (1-\tau)\cdot i + \tau \cdot r.\end{aligned} \tag{1}$$

Two conditions are required for (1) to be U-shaped. First, r must be a function of τ; more specifically, $r < i$ when τ is small and $r > i$ when τ exceeds a threshold. Second, i must be independent of τ. As we will show below, the latter requirement does not hold if investors are risk averse.

Consider the following numerical example. In time 1 (before interest payment), a firm generates income $\tilde{X}$ which can be either 200 or 60, with equal probabilities. The firm's expected value is therefore $\bar{X} = 130$. Suppose first that the firm is entirely financed with equity, and $V = S = 100$. Then the rate of return on equity has the following structure:

Rate of return on equity	Prob.
2.0	0.5
0.6	0.5,

and the expected rate of return on equity (i) is 1.3. Suppose now that the firm issues bonds (B') worth 50 at an interest rate (r) of 1.1. By assumption i remains unchanged, implying that

$$\frac{200 - 50 \times 1.1}{S'}0.5 + \frac{60 - 50 \times 1.1}{S'}0.5 = 1.3, \tag{2}$$

where S' is the new value of equity. Solving (2) for S' yields $S' \approx 58$, so that the new market value of the firm is $V' = B' + S' \approx 108$. The rate of return on equity is now:

Rate of return on equity	Prob.
2.5	0.5
0.1	0.5.

Hence investors ask for the same rate of return for an income flow with higher risk. As suggested by standard financial theory, this cannot happen if investors are risk averse.

The above example has already revealed the intuition of the MM theorem. Recognizing the relationship between τ and i, Modigliani and Miller's (1958) Proposition I asserts that *the market value of any firm is independent of its capital structure and is given by capitalizing its expected return at some rate ρ appropriate to its risk level.*

2.1 The methodology

Several approaches may be taken to examine the MM theorem. In this paper, we shall ask experimental subjects to evaluate the equity of firms with different capital structures separately over different markets. In other words, we place each firm in a separate market, thereby excluding arbitrage among the firms.

Arbitrage plays an important role in Modigliani and Miller's (1958) analysis for it helps to restore the stated equalities if Proposition I is violated. However, arbitrage is not necessary for the theorem to hold (see, e.g., Hirshleifer, 1966; Stiglitz, 1969). Additionally, allowing for arbitrage among firms may conceal the existence of preferences for firms with a particular capital structure because a few arbitrageurs could help eliminate this 'anomaly' at the market level. After all, as shown by Shleifer and Vishny (1997), arbitrage can never be complete in real financial markets. By excluding arbitrage among firms we can address a question of fundamental importance to the valuation of firms: *Do subjects systematically evaluate firms with different capital structures differently? If so, how?*

There is an additional strength in proceeding this way. Some empirical studies show that firms with different capital structures are evaluated similarly. Yet, this does not necessarily imply the irrelevance of capital structure to the value of the firm. The same result could be obtained if investors, in general, preferred some capital structure τ^* to some other capital structure τ', but these preferences were recognized by the firms that adjusted their capital structure towards τ^*. In this case, firms would be evaluated similarly simply because their capital structure is concentrated on τ^*. Our approach allows us to explore this possibility.

Note, however, that the exclusion of arbitrage may cause a potential problem. Since the law of one price can not be applied,[3] the investors' personal traits (like risk attitudes or wealth levels) become relevant and can affect results. For example, the valuation of different risky shares may differ depending on the portfolio that investors hold. Yet, this difference in valuations does not reflect the difference in shares *per se*, but it relates to the composition of the investors' portfolio. Since we want to focus on the valuation process *per se*, we need to minimize the impact of the participants' own traits. For this purpose, we adopt Stiglitz's (1969) general equilibrium model. In this model the MM theorem holds regardless of the participants' initial wealth conditions. Furthermore, the equilibrium solution is derived from the state-preference approach (Hirshleifer, 1966) which, compared to the more familiar mean-variance approach, does not make strong assumptions about risk attitudes or utility function shapes. Hence the results hold under more general conditions.

[3] The law of one price states that in an efficient market all identical goods must have only one price.

2.2 The model

Consider an economy with one firm and a set N of individual investors. The firm operates for two periods: t_0 (present) and t_1 (future). The uncertain income stream $\tilde{X}$ generated by the firm at t_1 is a function of the future state of the world θ. Let $\tilde{X}(\theta)$ denote the firm's income in state θ. Each investor $j \in N$ is endowed with an initial wealth ω^j, which is composed of a fraction α^j of S (the firm's equity) and B^j units of bonds. Since the economy is closed, we have

$$\sum_{j\in N} \alpha^j = 1, \quad \sum_{j\in N} B^j = B,$$

where B stands as before for the market value of the firm's bonds. By convention, one unit of bond costs one unit of money. Thus, investor j's budget constraint ($\forall j \in N$) is

$$\omega^j = \alpha^j S + B^j. \tag{3}$$

In addition, there exists a credit market where both the firm and the investors can borrow and lend at the rate of interest r. To be consistent with the assumptions of MM theorem, we suppose that the firm never goes bankrupt. Investors prefer more to less, and evaluate alternative portfolios in terms of the income stream they generate, i.e., investors' preferences are not state dependent.

2.2.1 The benchmark solution

In this section we shall prove the following proposition:

Proposition 1. *(1) If there exists a general equilibrium with a fully-equity financed firm having a particular value, then there exists another general equilibrium solution for the economy with the firm having any other capital structure but with its value unchanged. (2) Moreover, the property that the firm's value is unchanged holds in any equilibrium.*[4]

Let us now consider two economies. The firm in the first economy is only financed by equity. The firm in the second economy is financed by both equity and bonds. Let V_1 and V_2 denote the value of the firm in the first and second economy, respectively. We first show that there exists a general equilibrium solution with $V_2 = V_1$.

[4] Stiglitz (1969) only proves the first part of the proposition. We complete the proof by demonstrating the second part.

Start from the first economy. Since the firm issues no bonds, we have $V_1 = S_1$ (with S_1 being the value of the firm's equity in this economy) and $\sum_{j \in N} B_1^j = 0$. Here a positive (negative) value of B_1^j would mean that investor j invests (borrows) B_1^j units of money in (from) the credit market. Let $Y_1^j(\theta)$ stand for investor j's income in state θ of economy 1. With a portfolio consisting of α^j shares of the firm and B_1^j units of bonds, investor j's return in state θ can be written as:

$$\begin{aligned} Y_1^j(\theta) &= \alpha^j \tilde{X}(\theta) + r B_1^j \\ &= \alpha^j \tilde{X}(\theta) + r(\omega^j - \alpha^j V_1), \end{aligned} \tag{4}$$

which follows from (3) and $S_1 = V_1$.

Turn now to the second economy where the firm issues bonds with a market value of B_2. If S_2 denotes the value of the firm's equity in this economy, we have $V_2 = S_2 + B_2$ and $\sum_{j \in N} B_2^j = B_2$. Notice that the firm generates the same pattern of income stream $\tilde{X}$. With a portfolio consisting of α^j shares of the firm and B_2^j units of bonds, investor j's return in state θ is then given by:

$$\begin{aligned} Y_2^j(\theta) &= \alpha^j (\tilde{X}(\theta) - r B_2) + r B_2^j \\ &= \alpha^j (\tilde{X}(\theta) - r B_2) + r(\omega^j - \alpha^j S_2) \\ &= \alpha^j \tilde{X}(\theta) + r(\omega^j - \alpha^j V_2), \end{aligned} \tag{5}$$

where the third equality follows from $S_2 = V_2 - B_2$.

If $V_1 = V_2 = V^*$, the opportunity sets described by (4) and (5) are identical, i.e.:

$$Y_1^j(\theta) = Y_2^j(\theta) \qquad \forall \theta \ \text{ and } \ \forall j. \tag{6}$$

Thus, if α^j maximizes individual j's utility in the first economy, it still does in the second economy. This proves the first part of Proposition 1. It remains to show that $V_1 = V_2 = V^*$ holds in any equilibrium. when agents are strictly risk averse.

Suppose that there exists an equilibrium in the second economy where $V_2' > V_1 = V^*$. This in turn implies $S_2' = V_2' - B_2 > V^* - B_2 = S_2^*$. As the rate of return on equity is $\frac{\tilde{X} - rB}{S}$, with $\tilde{X}$ and B unchanged, the increase in the firm's equity value (from S_2^* to S_2') yields a decrease in the rate of return on equity. Such a decrease discourages the demand for equity in the second economy. Since the equity market of the second economy clears at $S_2^* = V^* - B_2$, it follows that there will be oversupply of equity when $S_2' > S_2^*$. But this is in contradiction with the assumption that $V_2' > V^*$ is an equilibrium. The other case $V_2' < V^*$ can be proved similarly.

Two features of the above model are worth noticing. First, no assumptions are made about investors' initial wealth. This is particularly helpful when conducting laboratory experiments because it reduces effects of sample selection on results. Second, except for the basic assumption that investors prefer more to less, no strong assumptions are made with respect to the shape of the utility function. This is also very appealing as measuring risk attitudes is tricky and not always accurate. Therefore, we expect experimental results based upon the above model to hold in fairly broad circumstances.

3 Experimental protocol

The computerized experiment was conducted in September 2007. Overall, we ran 3 sessions with a total of 78 participants, all being students at the Friedrich-Schiller University of Jena (Germany). The first session (with 14 participants) was conducted in the video lab of the Max Planck Institute of Economics. In this session, two subjects were put into one cubicle and acted as one agent.[5] We explicitly asked the participants to discuss loudly their strategy so that both their discussion and their game play could be recorded. The other two sessions (with 32 participants each) were run in the computer lab of the Max Planck Institute of Economics. The experiment was programmed in z-Tree (Fischbacher, 2007). Considering the complexity of the experimental procedures, only students with relatively high analytical skills were invited, i.e., students majoring in subjects such as mathematics, physics, engineering, economics, and business administration. Participants earned on average €15.90, inclusive of a €2.50 show-up fee.

3.1 General environments and procedures

Each experimental session consists of two subsequent phases. In the first phase, the lottery choice procedure developed by Holt and Laury (2002) is used to measure participants' risk attitudes.[6] Subjects are shown ten pairwise comparisons. In each comparison they are asked to choose between a safe option Y and a risky option X (see the instructions in the supplement for a complete representation of the ten comparisons). The payoff for option

[5] As only 14 subjects showed up, in two cubicles we had only one student.

[6] While there is currently no agreement about how to best assess risk preferences, the Holt and Laury procedure offers several advantages, among which its easy applicability. Additionally, no systematic bias has been found with respect to alternative methods of measuring risk (see Harrison and Rutström, 2008).

Y is fixed at 50 ECU.[7] The payoff for option X can be either 70 ECU with probability p or 30 ECU with probability $(1-p)$. In each successive comparison, p increases by 10 percentage points, until finally the last decision involves no uncertainty. Subjects' choices (in particular, the comparison at which they switch from Y to X) reveal their risk preferences.[8] At the end of the phase, one of the ten comparisons is randomly selected to determine the payoff based upon the chosen option. In order not to effect choices in the following phase, feedback on individual earnings in the first phase is given only at the end of the session (i.e., on completion of the second phase).

The second phase is devoted to testing the model outlined in Section 2.2. Participants are matched in groups of 8 (i.e., $N = 8$) and asked to evaluate eight firms in eight successive treatments via a market mechanism to be explained shortly (in the experiment, treatments are referred to as rounds). Group composition does not change throughout the phase.[9] Having one firm per treatment renders valuations independent from each other. To further discourage (potential) portfolio effects, only one treatment is randomly selected for payment at the end of the experiment.

Denote a treatment by T and the firm in the T-th treatment by f_T. Each f_T is represented by a risky asset that generates income stream

$$\tilde{X}(\theta) = \begin{cases} 1200 \text{ ECU} & \text{if } \theta = \text{good} \\ 800 \text{ ECU} & \text{if } \theta = \text{bad.} \end{cases}$$

Since our experimental design is rather complex (especially, the implemented market mechanism requires some cognitive effort), there is a need to minimize the impact of nuisance variables like fatigue, boredom, alertness, and computational skills. For this reason, we impose $Prob(\theta = \text{good}) = Prob(\theta = \text{bad}) = \frac{1}{2}$. Equally likely outcomes are often encountered in practice and easy for subjects to understand. Additionally, some researchers argue that in the case of equally likely outcomes, probabilities are less subjectively weighted, i.e., they are less distorted (e.g., Quiggin, 1982; Viscusi, 1989), and − even if they are distorted − this distortion does not affect preferences (Levy and Levy, 2002).

Each firm f_T has 100 shares outstanding and a market value of bonds B_T, so that firms differ only in their value of B_T. Since there is no bankruptcy, bonds are perfectly safe: one unit of experimental money invested in bonds yields a gross return of 1.5, implying a net risk-free interest rate of 0.5. Participants know that they can borrow any amount of

[7] ECU is the experimental currency unit. Participants are informed that 10 ECU equal 1 euro.

[8] Consistent subjects should only switch once from Y to X, and never back from X to Y.

[9] We have, therefore, one group in the the video lab session and four groups in each of the two computer lab sessions, yielding a total of nine groups.

experimental money from a bank at this interest rate. The sequence of bonds' values B_T chosen for characterizing the firms in the eight treatments is:

$$\begin{array}{ccccccccccccccccc} T: & 1 & & 2 & & 3 & & 4 & & 5 & & 6 & & 7 & & 8 \\ B_T: & 50 & \Rightarrow & 350 & \Rightarrow & 100 & \Rightarrow & 0 & \Rightarrow & 400 & \Rightarrow & 200 & \Rightarrow & 500 & \Rightarrow & 300. \end{array}$$

The first two treatments ($T = 1, 2$) are for training purposes. Their sole aim is to familiarize the participants with the decision process and its incentives (they cannot be drawn for payment).

We preferred not to present subjects with the complete capital structure of each firm (income flow and bonds' market value). Instead, we give subjects the eight equities (that is, the resulting return structure after payment of the interest on the bonds: $\tilde{X} - 1.5B_T$) and ask them to evaluate each equity. Thus, the participants are confronted with the following sequence of risky alternatives:

$$\begin{array}{l} 1\left\{\begin{array}{cc} \textit{Gain} & \textit{Prob.} \\ 11.25 & 0.5 \\ 7.25 & 0.5 \end{array}\right. \Longrightarrow 2\left\{\begin{array}{cc} \textit{Gain} & \textit{Prob.} \\ 6.75 & 0.5 \\ 2.75 & 0.5 \end{array}\right. \Longrightarrow 3\left\{\begin{array}{cc} \textit{Gain} & \textit{Prob.} \\ 10.50 & 0.5 \\ 6.50 & 0.5 \end{array}\right. \Longrightarrow \\ 4\left\{\begin{array}{cc} \textit{Gain} & \textit{Prob.} \\ 12.00 & 0.5 \\ 8.00 & 0.5 \end{array}\right. \Longrightarrow 5\left\{\begin{array}{cc} \textit{Gain} & \textit{Prob.} \\ 6.00 & 0.5 \\ 2.00 & 0.5 \end{array}\right. \Longrightarrow 6\left\{\begin{array}{cc} \textit{Gain} & \textit{Prob.} \\ 9.00 & 0.5 \\ 5.00 & 0.5 \end{array}\right. \Longrightarrow \\ 7\left\{\begin{array}{cc} \textit{Gain} & \textit{Prob.} \\ 4.50 & 0.5 \\ 0.50 & 0.5 \end{array}\right. \Longrightarrow 8\left\{\begin{array}{cc} \textit{Gain} & \textit{Prob.} \\ 7.50 & 0.5 \\ 3.50 & 0.5. \end{array}\right. \end{array} \tag{7}$$

A first reason for presenting each firm's equity as a 50/50 gamble is that some students (especially the economists) may have learned the MM theorem. Knowledge of the complete capital structure may induce them to be consistent with the theorem, thereby biasing the results. A second important reason is that such a presentation is very simple and allows us to effectively focus on the impact of different capital structures on the valuation of firms, minimizing any other confounding factor. If, in contradiction to MM theorem, firms with different capital structures are evaluated differently, this pattern should emerge also when people are shown simple 50/50 gambles. To put it differently, if the theorem is violated in a complex environment, it is unclear whether the violation is due to the complexity of the task or is genuine in nature. On the other hand, if the MM theorem is not supported even in a simple setting like ours, we can more safely presume that there is something inherently wrong with the model.

It could be argued that given our presentation of the capital structure, compliance with the MM theorem is to be expected.[10] Yet, despite our efforts to simplify the task, behaving in accordance with the theorem involves evaluating the various risky alternatives in a way that is not immediately straightforward. For example, subjects might not recognize the increase of systematic risk in equity until the leverage ratio reaches a certain threshold. In Davenport (1971), it is observed that there are substantial cost advantages to be gained by increasing leverage up to a certain range, and that there is also strong evidence that beyond a certain point further increases in the leverage ratio will lead to increases in the over-all cost of capital.

The specific procedures in each treatment T $(= 1, \ldots, 8)$ are as follows.

1. Subjects are presented with one of the risky alternatives shown in (7). This alternative corresponds to firm f_T's return on equity. In addition, each subject receives some initial endowment of the risky alternative and experimental money.[11]
2. A market mechanism becomes available. Via this mechanism subjects in each group can trade the risky alternative with each other. Traded quantities are required to be integers, and short selling is not allowed. Buying and selling prices must be within the range $[{}^{(800-1.5\times B_T)}/_{(100\times 1.5)}, {}^{(1200-1.5\times B_T)}/_{100}]$.[12]
3. After some time the market closes, and the net change in each agent's endowment of the risky alternative is considered. If the change is positive, for each purchased unit the agent pays a per-unit price equal to the market-clearing price; this amount is automatically deducted from the ECU he owns. If the change is negative, for each sold unit the agent receives a per-unit price equal to the market-clearing price; the received amount is automatically deposited in a bank and earns a net risk-free interest rate of 0.5.
4. Subjects are informed about (a) the market clearing price, and (b) their own final holdings of risky alternative and ECU.

To decrease income or wealth effects, information about the realized state of the world is given only at the end of the phase.[13] To provide subjects with strong marginal incentive and to increase the cost of mistakes, we pay subjects only the net profits they make.

At the end of the phase, each participant gets feedback on (a) the state of the world which

[10] For instance, Dell'Ariccia and Marquez (2010) show that when all liabilities are correctly priced, the MM irrelevance result applies to banks' organizational structure.

[11] How endowments are distributed among group members is described in the next section.

[12] Notice that the upper bound of the interval allows for non-rational behavior (as a further check on subjects' understanding of the situation).

[13] We provide this information at the end of $T = 1, 2$ (the two training treatments) to foster learning of the incentives.

is realized in each treatment, (b) his own net profit in each treatment, (c) the treatment randomly chosen for payment, and (d) his own final payoff.

3.2 Initial endowments and trading mechanism

The determination of the subjects' initial endowments is important, especially when subjects' payments are based on the net profits they make. Since the theoretical model suggests that agents' endowments in the different treatments should be the same (cf., Eq. (3)), a natural choice is to endow the participants with some amount of experimental money. However, in a general equilibrium model, this would require knowing the value of the firm *a priori*, i.e., before the experiment.

Taking into account the above considerations, in each treatment T initial endowments are as follows. Four out of the eight group members receive 12 units of T's risky alternative (i.e., 12% of firm f_T's 100 shares) and an amount of ECU equal to 12% of B_T; the remaining four group members receive 13 units of T's risky alternative and an amount of ECU equal to 13% of B_T. Subjects' ECU are automatically deposited into a bank. For each ECU deposited (borrowed), the bank offers (charges) a net risk-free interest rate of 0.5.

Although the theoretical model is silent about the market trading mechanism, the experimental choice of it is very important. Since we are interested in equilibrium outcomes, the trading mechanism should allow for sufficient learning and convergence. Moreover, it should be able to effectively aggregate private information (e.g., one's own valuation of the alternatives), and to minimize the impact of individual mistakes on market prices.

In security markets, the daily opening price of a stock is especially difficult to determine because of the high uncertainty associated with the stock's fundamental value after the overnight non-trading period. To set a reliable opening price, most major stock exchanges (e.g., New York, London, Frankfurt, Paris) use a call auction to open markets. Economides and Schwartz (1995) show that, by gathering many orders together, the call auction can facilitate order entry, reduce volatility, and enhance price discovery. These features make the call auction a perfect candidate for our market experiment. An alternative is the double-auction mechanism, which has quicker and more efficient convergence properties (see, e.g., Smith et al., 1982; Cason and Friedman, 1997; Kagel, 2004; Cason and Friedman, 2008), but is slower to implement and quite time consuming.

In all eight treatments, the call auction operates as follows. The participants have 3 minutes to submit buy or sell orders. They must specify (a) how many units of the risky alternative they want to buy or sell, and (b) the price at which they wish to trade each unit. After the 3 minutes, aggregate demand and supply schedules are derived from the individual orders. The market clearing (equilibrium) price is chosen to maximize volume of trades. The algorithm used to compute the market clearing price is reproduced in Appendix A.

To help subjects set a "reasonable" price and to increase learning, the 3 minutes are divided into three trading periods, each lasting 1 minute.[14] An "indicative" market clearing price is computed and announced at the end of the first two trading periods. This price is indicative in the sense that it suggests the price at which all eligible trades would occur if no orders were changed. Subjects know that they can revise their trade orders until the end of the allotted three minutes.

3.3 A (control) individual decision-making experiment

Testing the MM theorem via the above trading mechanism can provide helpful insights into how the market evaluates firms with different capital structures. However, for the model to hold, the markets must be always in equilibrium and, as remarked above, previous experimental studies have cast doubt on the ability of call markets to produce convergence to the competitive equilibrium quickly and efficiently (see Cason and Friedman, 1997, 2008, and references therein). Furthermore, even if the aggregate market outcome provides support for the MM theorem, this does not necessarily imply that every agent is making his utility-maximizing choice. Thus, following the suggestion of an anonymous referee, as a check on the robustness of our results, we ran a fourth session where 32 subjects participated in an individual decision-making experiment.

The session was conducted in the experimental laboratory of the Max Planck Institute. In accordance with the market experiment, only subjects with relatively high analytical skill were invited. Before starting the experiment, subjects had to answer three control questions. The session lasted about two hours including instructions and control questionnaire. The average payment was €17.90.

This control experiment maintains several features of the market experiment. Subjects play eight rounds, denoted once more by T. In each round T subjects are presented with one of the risky alternatives given in (7), thereby facing a firm with a specific capital

[14] To allow for sufficient learning, in each of the two training treatments the call auction opens for 6 minutes, and each trading period lasts 2 minutes.

structure. Half of the subjects are endowed with 12 shares of firm f_T and $12\% \times B_T$ ECU; the other half of the subjects are endowed with 13 shares of firm f_T and $13\% \times B_T$ ECU.[15] The experimental money is deposited into a bank, which pays a net interest rate of 0.5 for each ECU deposited. Similarly, subjects need to pay a net interest rate of 0.5 per borrowed ECU.

In each round (and thus for a given capital structure and endowment), four points on each subject's supply and demand curves for shares are elicited, corresponding to quantities of 1, 5, 9, 12 or 13. Specifically, a subject who is endowed with 12 (13) shares is asked to buy and sell 1, 5, 9, and 12 (13) units. In each round, the eight choices are elicited in a random order so as to exclude ordering effects.

As elicitation procedure we use the incentive-compatible Becker–DeGroot–Marschak mechanism (Becker et al., 1964). In the four 'buy' decisions, each subject is asked to report the highest price WTP(x) ($x = 1, 5, 9, 12$ or 13) at which he would be willing to buy each of the x units, where WTP(x) $\in [0.50, 12]$. In the four 'sell' decision, each subject is asked to submit the minimum selling price WTA(x) per unit, where WTA(x) $\in [0.50, 12]$. At the end of each round, one of the eight decisions is randomly selected. A further draw from a uniform distribution determines a random number $\pi \in [0.50, 12]$ and the selected decision (either buy or sell) is executed depending on whether or not π exceeds the price specified by the subject.[16]

4 Results on the individual decision-making experiment

In this section, we present the results of the control experiment where valuations are defined as reservation prices that a person is either willing to pay (WTP) to purchase x units or willing to accept (WTA) to forgo x units. Table 1 provides average valuations, separately for the type of trade, the eight bonds' values, and the four traded quantities.

One thing which stands out immediately is that WTP is generally lower than WTA. The difference is significant not only when we average over all four traded quantities ($p < 0.01$, paired Wilcoxon test), but also when we consider the four feasible quantities separately ($p < 0.05$ for all four one-sided paired Wilcoxon tests). Additionally, the difference between WTP and WTA is larger, the more units need to be traded (on average: -131.46 for $x = 1$;

[15] Shares are referred to as units of the risky alternative in the instructions.

[16] If the payoff-relevant decision is a buy decision and WTP(x) $\geq \pi$, the subject purchases the x units at a unit price of π. If the payoff-relevant decision is a sell decision and WTA(x) $\leq \pi$, the subject sells the x units at a unit price of π.

Table 1: Mean valuations for each value of bonds and each traded quantity, separately for buy and sell decisions

Bonds	Buy decisions (WTP)				Sell decisions (WTA)			
value	1 unit	5 units	9 units	12,13 units	1 unit	5 units	9 units	12,13 units
0	775.19	657.53	640.41	640.22	848.81	842.91	861.06	815.19
50	765.03	609.16	560.62	575.81	883.16	825.91	852.41	916.72
100	687.22	648.06	606.34	624.28	825.31	867.44	814.25	825.72
200	734.81	609.25	580.62	499.59	814.06	840.69	847.25	878.41
300	684.09	618.75	539.22	541.12	915.31	839.56	885.16	905.78
350	727.03	639.41	654.12	595.69	875.69	848.84	855.97	867.94
400	661.88	687.69	621.69	543.94	831.25	824.00	851.12	879.81
500	726.94	657.75	555.47	515.88	820.25	836.50	878.53	839.59
ALL	720.27	640.95	594.81	567.07	851.73	840.73	855.72	866.14

-199.78 for $x = 5$; -260.91 for $x = 9$; -299.08 for $x = 12, 13$).

Participants' endowment of experimental money varies from round to round, and the ECU at their disposal may affect willingness to pay. It is therefore worthy to investigate whether buy decisions vary with the ECU endowment. To this aim we compute, for each x and each subject, the average WTP(x) separately for $B_T \leq 200$ and $B_T \geq 300$. Comparing the 32 individual average WTP(x) when $B_T \leq 200$ and when $B_T \geq 300$, it is not possible to reject the null hypothesis that, for each x, the two series have identical distributions ($p > 0.10$ for all four traded quantities, two-sided Wilcoxon signed rank tests). This suggests that subjects' willingness to pay is not influenced by the size of the ECU endowment.

The utility maximization assumption in Proposition 1 (Equation 6) implies that if all shares were owned by individuals identical to a certain subject, the value of the firm resulting from the price reported for a given quantity should be the same across all capital structures. That is, if we denote by $V_{f_{\tau'}}(x)$ and $V_{f_{\tau^*}}(x)$ the value of the firms with capital structure, respectively, τ' and τ^* when x shares are traded, the proposition requires that for each x: $V_{f_{\tau'}}(x) = V_{f_{\tau^*}}(x)$ for all $\tau', \tau^* = 1, 2, \ldots, 8$, and $\tau' \neq \tau^*$.

To test this assumption, for each x we compare − via a series of Wilcoxon signed-rank tests − the observed valuations across the eight capital structures. For each x we therefore perform 28 comparisons. With four traded quantities, we have $28 \times 4 = 112$ comparisons for the buy decisions and 112 comparisons for the sell decisions. Using $p < 0.05$ as the significance level, a significant difference is detected for 5.35% (6 out of 112) comparisons in the buy decisions, and for 2.68% (3 out of 112) comparisons in the sell decisions.[17]

[17] All significant differences are observed when the subjects trade the maximum quantity of shares ($x = 12$ or 13).

Table 2: Regression results on reservation prices

Expl. Variable	Coefficient	Std. Error	t-statistic	p-value
υ	729.7523**	25.6347	28.4674	0.0000
B_T	-0.0681	0.1166	-0.5840	0.5593
B_T^2	0.0001	0.0002	0.3405	0.7335
$Trade_s$	131.4570**	21.2012	6.2004	0.0000
$x5$	-79.3242**	21.2012	-3.7415	0.0002
$x9$	-125.4609**	21.2012	-5.9176	0.0000
$x123$	-153.2070**	21.2012	-7.2263	0.0000
$Trade_s \times x5$	68.3242**	29.9830	2.2788	0.0228
$Trade_s \times x9$	129.4492**	29.9830	4.3174	0.0000
$Trade_s \times x123$	167.6211**	29.9830	5.5905	0.0000
Std. dev. of the random effects		$\sigma_u = 102.2934$		
Std. dev. of error term		$\sigma_e = 239.8642$		
Number of observations		2048		

** Significant at the 1% level.

Thus, overall, we do not find strong evidence against the utility maximization assumption implied by Proposition 1.

Finally, we run a linear regression with mixed effects to explore carefully the impact of bonds on the valuation of the firms. Explanatory variables are the intercept (υ), the bonds' value (B_T), the square of the bonds' value (B_T^2), the dummy $Trade_s$ (which equals 0 for the WTP and 1 for the WTA), the four traded quantities ($x1$, $x5$, $x9$, and $x123$), and the interaction between traded quantity and type of trade. Random effects are the 32 individual subjects. Formally, the model is as follows:

$$\begin{aligned} V_i \;&=\; \upsilon + u_i + \beta_1 \cdot B_T + \beta_2 \cdot B_T^2 + \beta_3 \cdot Trade_s + \beta_4 \cdot x5 + \beta_5 \cdot x9 \\ &\quad + \beta_6 \cdot x123 + \beta_7 \cdot Trade_s \cdot x5 + \beta_8 \cdot Trade_s \cdot x9 \\ &\quad + \beta_9 \cdot Trade_s \cdot x9 + \beta_{10} \cdot Trade_s \cdot x123 + \varepsilon_i, \end{aligned}$$

where $i \in \{1, 2, \ldots, 32\}$ denotes the 32 subjects, $u_i \backsim N(0, \sigma_u^2)$ denotes the random effects in the intercept for each subject, and $\varepsilon_i \backsim N(0, \sigma_e^2)$. The results of the regression are presented in Table 2.

The coefficients of both B_T and B_T^2 are not significant, pointing to a consistency with the MM theorem, i.e., bonds have no effect on the valuation of firms. The remaining estimated coefficients confirm the results discussed above: (a) WTA exceed WTP (the coefficient of $Trade_s$ is positive and significant); (b) the more units need to be traded, the lower the WTP and the higher the WTA.

The above results are based on individual valuations of firms. In reality, the valuation of firms is more a market outcome.[18] We therefore turn to the analysis of the main market experiment.

5 Results on the market experiment

Risk attitudes play an important role in markets. In fact, trade can occur only when agents have heterogeneous risk preferences. In the Holt and Laury (2002) lottery choice procedure − that we employed in the first phase of the market experiment − the subjects' total number of safe choices can be used as a proxy for risk aversion. Denote this proxy by γ. Obviously, the larger the value of γ, the higher the degree of risk aversion. We find considerable variation across people and a median γ-value of 6, which suggests that most participants are risk averse. Furthermore, all subjects are consistent, i.e., they have a single switch point.[19]

According to standard portfolio theory, relatively risk averse individuals should hold a greater portion of their wealth in safe deposits, whereas more risk tolerant individuals should prefer higher-risk assets. In line with this assertion, we find that the correlation between γ and subjects' end-holdings of experimental money is significantly positive (Spearman's $\rho = 0.09$, $p < 0.01$), and the correlation between γ and subjects' end-holdings of the risky alternative is significantly negative (Spearman's $\rho = -0.091$, $p < 0.05$).

As noted above, given the complexity of our experiment, we invited only students with relatively high analytical skills. Moreover, prior to the experiment, subjects had to answer a control questionnaire testing their comprehension of the rules. We suspect, however, that some subjects did not pick up all facets of the problem. First, during the administration of the control questionnaire, a few people encountered difficulties in handling a gross interest rate of 1.5. Second, in the post-experimental questionnaire, a number of subjects explicitly complained about the difficulty of the task. It is then important to check that the experimental results are reliable. To this aim we compare the values of the firms

[18] With each subject's demand and supply points in hand, we could create artificial markets and compute the value of the firms from the market clearing price of these artificial markets. Yet, due to the huge difference between WTP and WTA, no market clearing price existed in most artificial markets.

[19] Such a consistency may be a consequence of the stringent selection criteria used for recruiting subjects.

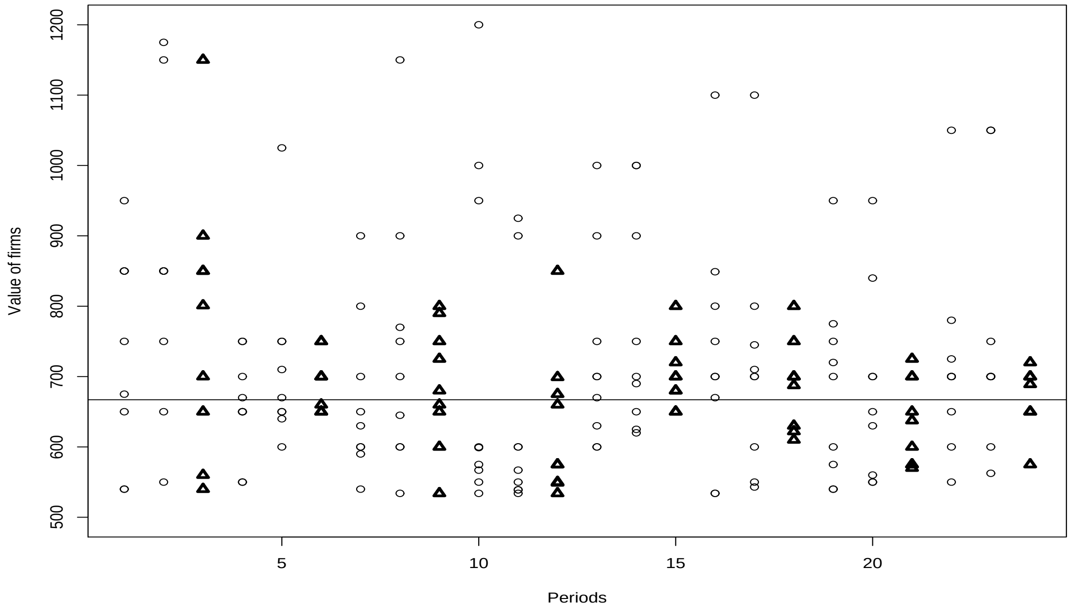

Figure 1: Empirical values of the firms across periods

implied by the experimental data with the theoretical value resulting from the assumption of rational risk neutral agents.[20]

Since the risk-free gross interest rate was 1.5, a risky asset paying either 1200 or 800 with equal probabilities should be valued at $(1200 \times 0.5 + 800 \times 0.5)/1.5 = 667$ by risk neutral rational agents. Figure 1 displays the development of the firms' empirical values across periods. On the horizontal axis, three consecutive periods represent one treatment, i.e., periods 1–3 correspond to $T = 1$, periods 4–6 correspond to $T = 2$, etc. The circles denote the firms' indicative values, calculated from the indicative market clearing prices determined at the end of the first two trading periods of each treatment. The triangles denote the firms' final values, calculated from the final market clearing prices determined in the third and last trading period of each treatment.

The median values of the firms are: 700 when all data points are used, 677.5 when the indicative prices are excluded from the sample, and 667.5 when both indicative prices and training periods are excluded. Wilcoxon signed-rank tests indicate that the central tendency of each of the three empirical distributions does not differ from 667 (lowest p-

[20] The empirical value of a firm is obtained by adding the elicited market value of equity and the market value of bonds.

value = 0.79). Note the marked contrast with the results of the control experiment. When valuations are the result of individual decision making, reservation prices are far from 667 (see Table 2), and the difference between WTP and WTA does not allow for the existence of a competitive equilibrium in most 'artificial' markets. The finding that the market more closely matches rational choice theory is in line with past literature indicating that exchange institutions "serve to push behavior more toward the Homo Economicus fiction we assume in our models" (Shogren and Taylor, 2008, p. 34).[21]

We also observe that enough trading takes place at prices that are close to the mean of the three market-clearing prices determined in each treatment. Call this mean $\bar{P}^*_T$. On average, in each treatment, groups buy 23.5 units and sell 26.83 units at prices falling in the interval $[\bar{P}^*_T - 2, \bar{P}^*_T + 2]$. Therefore, in spite of the complexity of the experimental procedures and the difficulty of the task, subjects perform surprisingly well and the results are reasonable.

Figure 1 shows that circles are more volatile than triangles, especially in the last treatments. This is not surprising because the markets in the first two trading periods are not yet mature (subjects get more adept as time passes), and because the indicative prices are not binding. Consequently, the following analysis shall consider only the final market clearing prices and the six payoff-relevant treatments, unless otherwise stated.

A valid concern here, like in the (control) individual decision-making experiment, is that subjects may have an aversion to borrow experimental money. Accordingly, the lower their initial endowment of ECU, the less units of shares they would buy. This, of course, would make the market values of the firms dependent on the people's money endowment. In order to test for this possibility, we perform an analysis similar to that in the previous section. For each independent group, we calculate the average value of the firms when $B_T \leq 200$ (denoted by $\overline{V}_{B\leq 200}$), and the average value of the firms when $B_T \geq 300$ (denoted by $\overline{V}_{B\geq 300}$). A two-sided Wilcoxon signed rank test comparing the nine $\overline{V}_{B\leq 200}$-means with the nine $\overline{V}_{B\geq 300}$-means does not reject the null hypothesis of equality of the two series ($p = 0.26$). We can therefore conclude that subjects' money endowment does not affect the firms' value.

We conclude this subsection by noticing that not only Proposition 1 is the result of individual maximization, it also imposes a strong condition on individual portfolios. In particular, the proposition implies that individuals' holdings of equity should be the same

[21] Chu and Chu (1990) show that the incidence of preference reversals is reduced in a market-like environment. Brocas and Carrillo (2001) finds that direct competition alleviates inefficiencies due to time inconsistency.

under the different capital structures. An ANOVA analysis of individual shareholdings across the different capital structures cannot reject this hypothesis ($p > 0.10$).

5.1 The effect of leverage on the cost of capital

We now turn to our main research question and examine the empirical relationship between cost of capital and value of the firm derived from our data. As outlined in Section 2, there are two main competing views on this relationship. The first, the MM theorem, holds that the value of the firm is independent of its capital structure. The second is that the relationship is U-shaped: the weighted average cost of capital first decreases with the value of bonds and then increases. In the following, we shall compare these two views and see which best organizes the data.

Figure 2 reports the average values of the firms as a function of the values of the bonds, with average over the 9 independent groups. Since group heterogeneities may blur the picture, the same relationship is presented in Figure 3 for the 9 groups separately. To give a more general account of the data, both indicative values (circles) and final values (triangles) are illustrated. The continuous line in each panel of Figure 3 denotes the group mean value of the firms, computed using only final market clearing prices.

The MM theorem suggests that any increase in leverage leads to an increase in the systematic risk of equity, which in turn leads the shareholders to demand higher returns. How well could subjects recognize changes in systematic risk due to changes in the capital structure? To address this issue, we compute the correlation between the value of equity and the value of bonds. Consistent with the MM theorem, we find that this correlation is negative and close to unity (Spearman's $\rho = -0.93$, $p < 0.01$).

To examine the relationship between the value of the firm and the value of the bonds more precisely, we run two linear mixed-effects regressions. The first regression models the market values of the firms as a linear function of the value of the bonds (B_T), the square of the value of the bonds (B_T^2), and period (t). Formally:

$$V_i = v + u_i + \beta_1 \cdot B_T + \beta_2 \cdot B_T^2 + \beta_3 \cdot t + \varepsilon_i, \tag{8}$$

where $i \in \{1, 2, \ldots, 9\}$ denotes the 9 independent groups, $u_i \backsim N(0, \sigma_u^2)$ denotes the random effects in the intercept for each group, and $\varepsilon_i \backsim N(0, \sigma_e^2)$.

The results (presented in Table 3) reveal that the coefficients of both B_T and B_T^2 are

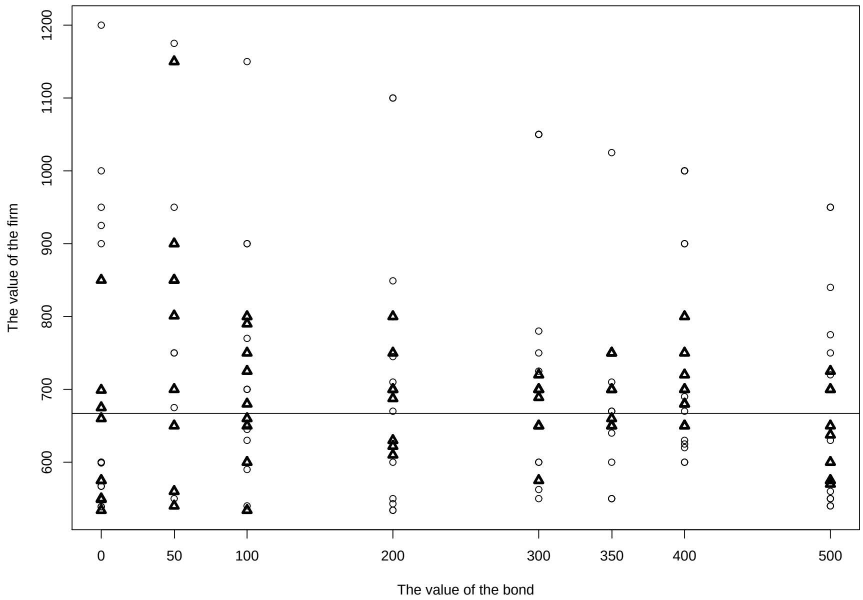

Figure 2: Average values of the firms conditional on the market value of the bonds

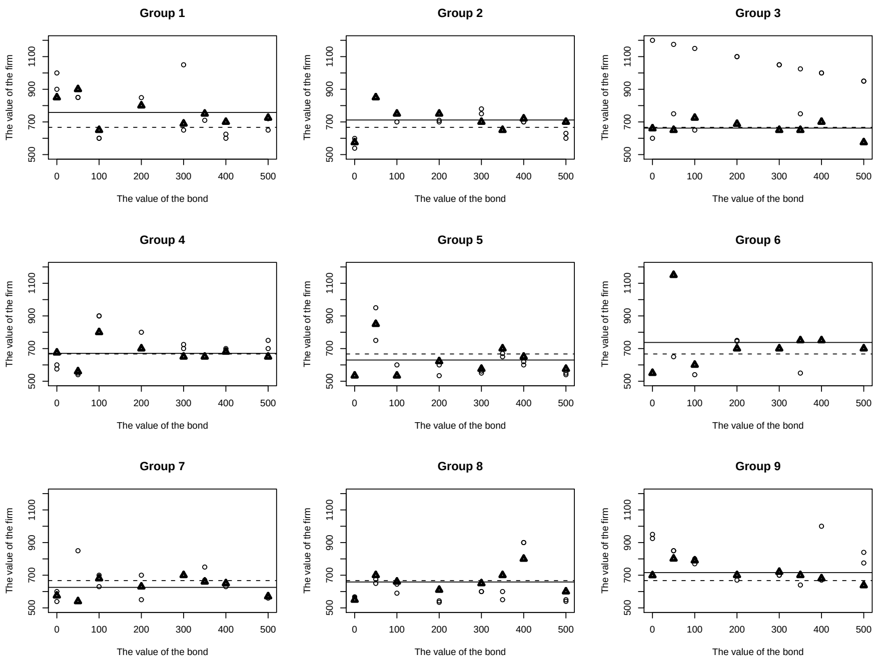

Figure 3: Values of the firms conditional on the market value of the bonds, separately for each of the 9 independent groups

Table 3: Regression results on the market values of the firms

Expl. Variable	Coefficient	Std. Error	t-statistic	p-value
υ	677.4643**	30.6054	22.1354	0.0000
B_T	0.6457**	0.1902	3.3956	0.0015
B_T^2	−0.0011**	0.0003	−3.2616	0.0022
t	−4.2244*	2.1541	−1.9611	0.0565
Std. dev. of the random effects	$\sigma_u = 38.8864$			
Std. dev. of error term	$\sigma_e = 58.0902$			
Number of observations	54			

** Significant at the 1% level. *Significant at the 10% level.

Table 4: Regression results on the weighted average cost of capital

Expl. Variable	Coefficient	Std. Error	t-statistic	p-value
κ	1.5305**	0.0674	22.7151	0.0000
τ	−0.9702**	0.2453	−3.9546	0.0003
τ^2	1.0941**	0.2642	4.1418	0.0002
t	0.0069	0.0047	1.4620	0.1512
Std. dev. of the random effects	$\sigma_u = 0.0886$			
Std. dev. of error term	$\sigma_e = 0.1262$			
Number of observations	54			

** Significant at the 1% level.

statistically significant. Moreover, their signs are indicative of a U-shaped cost of capital curve. The coefficient of t is weakly significant, suggesting that some kind of learning is taking place.

In the second regression, the dependent variable is the weighted average cost of capital (WACC), calculated as the expected return of the firm (i.e., 1000) divided by the market value of the firm. Independent variables are the leverage ratio (τ), measured as the market value of the bonds divided by the market value of the firm, the leverage ratio squared (τ^2), and period (t). The formal equation is similar to (8), and the estimated equation turns out as follows (see Table 4):

$$\text{WACC} = 1.5305 - 0.9702 \cdot \tau + 1.0941 \cdot \tau^2,$$

which offers further support for the U-shaped cost of capital approach.

6 Conclusions

When the leverage of a firm increases, the systematic risk of the firm's equity increases as well. Modigliani and Miller (1958) show that the higher return demanded by equity holders exactly offsets the lower market value of the bonds and, as a result, the weighted average cost of capital remains the same. This paper is a first attempt to investigate the Modigliani-Miller theorem in laboratory markets where agents can trade shares of firms generating the same income stream via different capital structures. The design includes some features intended to give the theorem its "best shot" at organizing the data. Furthermore, as the theorem is based on individual utility maximization, we also performed a control individual decision-making experiment where we elicited several points on the individual supply and demand curves for shares.

The results identify some strengths and some weaknesses of Modigliani and Miller's approach. On the one hand, subjects recognize the increased systematic risk of equity when leverage increases, and thus demand a higher return for bearing this risk. On the other hand, the regression results are supportive of a U-shaped cost of capital curve, suggesting that subjects tend to underestimate the riskiness of low-leveraged equity and to overestimate the riskiness of high-leveraged equity.

We do not regard our results as a rejection of the MM theorem. First, its main proposition does a good job of organizing the data in the control experiment. Second, some of its hypotheses cannot be rejected in the market experiment as well. The lack of full support for the theorem may be due to market "imperfections", defined as anything that interferes with trade, therefore causing a rational market participant either to deviate from holding the market portfolio or to depart from his preferred risk level (see, e.g., DeGennaro, 2005). For instance, the use of a single call market and the exclusion of arbitrage opportunities could have affected our findings. Understanding whether these design choices are important or the violation of the theorem is genuine in nature may provide a fruitful avenue for future research.

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Appendix A: Algorithm to compute the market clearing price in the call auction

The following algorithm was used to calculate the market clearing price:

1. Any order for buying Q units at price P_b is transformed into a vector where P_b is repeated Q times, so that each element of this vector can then be treated as a single buy order at price P_b. The individual vectors are then combined into a general buy vector, which is sorted by buying price in descending order (from highest to lowest). A similar operation is done for all sell orders except that the resulting vector is sorted by selling price from lowest to highest. In this way, aggregate demand and supply schedules are constructed:

$$\begin{array}{ll} \text{The buy vector} & (P_b^1,\ \ P_b^2,\ \ \ldots,\ \ P_b^i,\ \ P_b^{i+1},\ \ \ldots, P_b^{end}), \\ \text{The sell vector} & (P_s^1,\ \ P_s^1,\ \ \ldots,\ \ P_s^i,\ \ P_s^{i+1},\ \ \ldots, P_s^{end}), \end{array}$$

   where $P_b^i \geq P_b^{i+1}$ and $P_s^i \leq P_s^{i+1}$.

2. These two vectors are then pairwise compared (P_b^i and P_s^i), and this searching process continues until a first pair i where $P_b^i < P_s^i$ is found. Obviously, a market clearing price should satisfy

$$P_b^i < P < P_s^i,$$

   since these two orders should not be executed. Meanwhile, P_b^{i-1} and P_s^{i-1} should be exchangeable at the market clearing price, which implies

$$P_s^{i-1} < P < P_b^{i-1}.$$

   Combining these two conditions, the market clearing price should satisfy

$$max\{P_s^{i-1}, P_b^i\} < P^* < min\{P_b^{i-1}, P_s^i\}. \tag{9}$$

   In the experiment, P^* is set to be $\frac{max\{P_s^{i-1}, P_b^i\} + min\{P_b^{i-1}, P_s^i\}}{2}$.

3. If there is an excess demand or supply at this market clearing price, only the minimum quantity of the buy or sell orders is randomly selected for execution.

4. It is possible that a market clearing price may not be found by this way if $P_b^1 < P_s^1$ or $P_b^{end} > P_s^{end}$. In this case, $P_s^1 - 0.01$ is chosen to be the market clearing price if $P_b^1 < P_s^1$, and $P_b^{end} + 0.01$ is chosen to be the market clearing price if $P_b^{end} > P_s^{end}$.

S1 Instructions for the market experiment (originally in German)

Welcome to this experiment. Please cease any communication with other participants, switch off your mobiles, and read these instructions carefully. If you have any questions, please raise your hand. An experimenter will come to you and answer your question individually. It is very important that you obey these rules, since we would otherwise be forced to exclude you from the experiment and all related payments.

In the experiment you will earn money according to your own decisions, those of other participants, and random events. The show up fee of €2.50 will be taken into account in your payment. In the experiment, we shall speak of ECU (Experimental Currency Units) rather than Euro. The total amount of ECU you earn will be converted into Euro at the end of the experiment. The conversion rate is 10 ECU = 1 Euro.

Please note that it is possible to make a loss in this experiment. If this happens, you would have to come to the Max Planck Institute and do some office work. By this, you will be paid at €7 per hour. However, this can only be used to repay your losses (not to increase your earnings).

The experiment will consist of 2 phases. The following instructions only refer to the first phase. Instructions for the second phase will be given to you after the first phase is finished. Both phases of the experiment will be paid, and your performance in the first phase does not influence your payment in second phase.

DETAILED INFORMATION FOR THE FIRST PHASE

For ten different situations, you have to choose one of two options X or Y. These 10 different situations will be presented on screen. Option Y pays out 50 ECU with certainty. Option X yields 2 possible monetary outcomes, 70 ECU and 30 ECU that are paid out according to the probabilities noted. While the two possible outcomes remain constant in all 10 situations, their probabilities vary. Options X and Y will be presented as shown in Table 1.

For instance, in situation 1 of the table, option X yields 70 ECU with probability $1/10$ and 30 ECU with probability $9/10$. Option Y yields 50 ECU with certainty.

On the right hand side, you have to click the option you choose. For option X click the left circle, and for option Y the right circle. Please note that at the end of the experiment (after phase 2), only one of these 10 situations will be randomly selected to be paid out. All situations are equally likely, i.e., the computer picks a random number from 1 to 10

Please, choose one of the two options in each of the 10 cases.

	Option X	Option Y	
1	with $1/10$ a gain of 70 ECU, with $9/10$ a gain of 30 ECU	a sure gain of 50 ECU	X ◯ ◯Y
2	with $2/10$ a gain of 70 ECU, with $8/10$ a gain of 30 ECU	a sure gain of 50 ECU	X ◯ ◯Y
3	with $3/10$ a gain of 70 ECU, with $7/10$ a gain of 30 ECU	a sure gain of 50 ECU	X ◯ ◯Y
4	with $4/10$ a gain of 70 ECU, with $6/10$ a gain of 30 ECU	a sure gain of 50 ECU	X ◯ ◯Y
5	with $5/10$ a gain of 70 ECU, with $5/10$ a gain of 30 ECU	a sure gain of 50 ECU	X ◯ ◯Y
6	with $6/10$ a gain of 70 ECU, with $4/10$ a gain of 30 ECU	a sure gain of 50 ECU	X ◯ ◯Y
7	with $7/10$ a gain of 70 ECU, with $3/10$ a gain of 30 ECU	a sure gain of 50 ECU	X ◯ ◯Y
8	with $8/10$ a gain of 70 ECU, with $2/10$ a gain of 30 ECU	a sure gain of 50 ECU	X ◯ ◯Y
9	with $9/10$ a gain of 70 ECU, with $1/10$ a gain of 30 ECU	a sure gain of 50 ECU	X ◯ ◯Y
10	a sure gain of 70 ECU	a sure gain of 50 ECU	X ◯ ◯Y

Table 1: Presentation of the options

and thereby determines the situation that will be paid out. If in the randomly selected situation you pick Y, then you get 50 ECU for sure. Otherwise, to determine your payment, a second random number Z in the range of 0 to 10 (with 2 decimals) is generated. For the case described above, where probabilities for option X are $1/10$ and $9/10$, the outcome is determined as follows. If the random number Z falls between 0 and 1 ($0 \leq Z \leq 1$), i.e., with probability $1/10$, option X yields 70 ECU. If the random number Z falls between 1 and 10 ($1 < Z \leq 10$), i.e., with probability $9/10$, the option yields 30 ECU.

DETAILED INFORMATION FOR THE SECOND PHASE

In this phase there are 32 participants, divided into 4 groups with 8 participants each. You belong to one of these 4 groups, and you will play with the same 7 other participants repeatedly in this phase. The identities of the 7 participants you play with will not be revealed to you at any time.

This phase consists of 6 rounds. At the beginning of each round, we will grant you a interest free credit bundle, which is composed of M_{ini} amount of ECU and N_{ini} units of risky alternative R. The M_{ini} ECU will be automatically deposited into a bank which pays you 1.5 times the deposited amount for sure. Each unit of risky alternative R allows you to gain:

- ▷ a high amount H of ECU with 50% probability;
- ▷ a low amount L of ECU with 50% probability.

The amounts H and L will vary from round to round and will be revealed to you at the beginning of each round.

You can trade risky alternatives with the 7 other participants in your group. The ECU needed for buying risky alternative R will be deducted from the ECU you have in the bank. The ECU you get from selling risky alternative R will be automatically deposited into the bank.

The trading in each round lasts 3 minutes. It operates as follows.

1. You must state a) whether you want to buy or sell units of risky alternative R, b) how many units you want to buy or sell, and c) the price per unit. The request takes the following form:

   I want to buy (or sell) _ units of risky alternative R at price _ per unit.

   You will not see the requests made by the other 7 group members.
2. After one minute, all requests of your group will be aggregated, and a **suggestive price** P will be published to each member of your group. This price is chosen to maximize the exchanged units of risky alternative R. The suggestive price P is not the actual trading price; it only indicates that if the current requests are not changed until the end of the 3 minutes, then the requests satisfying the following three conditions will be executed at the suggestive price P

   Trading Condition 1: all **buy** requests with price higher than P;

   Trading Condition 2: all **sell** requests with price lower than P;

   Trading Condition 3: for **sell** or **buy** requests at the suggestive price, only the minimum of the two will be traded. That is, if demands are larger than supplies, these sell requests will be randomly allocated to buy requests; if supplies are larger than demands, these buy requests will be randomly allocated to sell requests.
   Suppose, for example, that the suggestive price is $P = 9$, and you requested to buy 5 units of risky alternative R at the price of 17 ECU per unit. Since $17 \geq 9$ (Trading Condition 1), these requests will be executed at $P = 9$ (not at 17). If, instead, you requested to buy 5 units of R at the price of 8 ECU per unit, this request will not be executed because $8 < 9$. If you requested to buy 10 units of R at $P = 9$, but there are only 5 sell units at 9, then you will only get 5 units.
3. After knowing the suggestive price, you can change your requests within the next one minute.
4. At the end of the second minute, all requests will be once again aggregated to give a new suggestive price, and you can adjust your requests in the next 1 minute.
5. At the end of 3 minutes, the trading ceases and a unique actual trading price P^* is published, which is the same for all the 8 participants in the your group. All requests

satisfying the three trading conditions (**Trading Condition 1,2,3**) described in step 2 above are executed.

The ECU you have in the bank after the trading (M_{end}) will be multiplied by 1.5. Depending on your trading activities, this amount can also be negative. The units of risky alternative R you have after the trading N_{end} allows you to obtain:

- $N_{end} \times H$ ECU with 50% probability;
- $N_{end} \times L$ ECU with 50% probability.

However, the credit you have taken has to be paid back fully, i.e., you will have to pay back M_{ini} and N_{ini} units of risky alternative R. The remaining ECU will be your round net profit (which can also be negative).

Suppose that we grant you M_{ini} ECU and N_{ini} units of risky alternative R, and after the trading you have M_{end} ECU in the bank and N_{end} units of the risky alternative. If the price of a unit of risky alternative R at the end of the trading is P^*, and the risky alternative R obtains H, then:

- the value of your initial bundle (M_{ini} ECU and N_{ini} units of risky alternative R) is $M_{ini} + N_{ini} \times P^*$;
- the value of your final bundle (M_{end} ECU and N_{end} units of risky alternative R) is $1.5\, M_{end} + N_{end} \times P^* + N_{end} \times H$.

Your round earnings is calculated as follows:

$$\begin{aligned} \textit{Round earnings} &= \textit{the value of your final bundle} - \textit{the value of your initial bundle} \\ &= 1.5\, M_{end} + N_{end} \times P^* + N_{end} \times H - M_{ini} - N_{ini} \times P^* \end{aligned}$$

The information you receive

At the end of each round, you will receive information about 1) the actual trading price P^*, and 2) your final holdings of ECU (M_{end}) and units of risky alternative R (N_{end}).

At the end of this phase, you will receive information about 1) the outcome that risky alternative R obtains in each round, 2) your net profit in each round, 3) the round chosen for payment, and 4) your final experimental earnings.

Your experimental earnings in this phase

At the end of this phase, only *one* round will be randomly chosen for payment. The resulting amount will be converted to euros and paid out in cash.

Two training rounds

In order to get acquainted with the structure of the experiment, you will have two training rounds before the real experiment starts. These two rounds will not be chosen for payment.

Before the experiment starts, you will have to answer some control questions to ensure your understanding of the experiment.

S2 Instructions for the control experiment

Welcome! You are about to participate in an experiment funded by the Max Planck Institute of Economics. Please switch off your mobiles and remain silent. It is strictly forbidden to talk to other participants. Please raise your hand whenever you have a question; one of the experimenters will come to your aid.

You will receive €2.50 for showing up on time. Besides this, you can earn more. But there is also a small possibility of ending up with a loss. The show-up fee and any additional amounts of money you may earn will be paid to you in cash at the end of the experiment. Payments are carried out privately, i.e., the others will not see your earnings.

Throughout the experiment, we shall speak of ECU (Experimental Currency Units) rather than Euro. The conversion rate is 10 ECU = 1 Euro.

You will not interact with any other participant. Your earnings during the experiment will depend on your own decisions and on chance. Think carefully and make your decisions at the pace you feel comfortable with. There are no right or wrong decisions.

The experiment consists of 8 rounds. You will be facing the same decision situation in each round.

The situation you will face in each round

At the beginning of each round you will be endowed with M_{ini} ECU and N_{ini} units of a risky alternative. The value of M_{ini} will vary from round to round. The value of N_{ini} can be either 12 or 13. You will be told your initial endowment M_{ini} of ECU and whether you own 12 or 13 units of the risky alternative at the beginning of each round.

The **M_{ini} ECU in your possession** will be automatically deposited in a bank which pays you 1.5 times the deposited amount *for sure* at the end of the round. Thus, if you have 100 ECU in the bank, you get $100 \times 1.5 = 150$ ECU at the end of the round. Similarly, if you have 50 ECU in the bank, you get $50 \times 1.5 = 75$ ECU.

***Each unit* of the risky alternative** allows you to gain

- ▷ a high amount H of ECU with 50% probability;
- ▷ a low amount L of ECU with 50% probability.

Suppose that $H = 10$ and $L = 5$. Then each unit of the risky alternative allows you to gain 10 ECU with 50% probability and 5 ECU with 50% probability. If you own 12 units of this risky alternative, you have either 120 ECU with 50% probability or 60 ECU with 50% probability. The amounts H and L will vary from round to round and will be revealed to you at the beginning of each round. The risky alternative will be always presented in the following form:

Gain	*Probability*
H ECU	50%
L ECU	50%

What you have to do

In each round you will be asked to buy further B units of the risky alternative you confront in that round, and to sell S units of it. There will be four buy decisions and four sell decisions. These eight decisions will differ in the units of the risky alternative you must buy (B) and the units of the risky alternative you must sell (S). The values of B and S will be displayed on your computer screen at the time of your decisions.

• *Buy decisions*

For the buy decisions, you must report the highest amount of ECU for which you would be willing to buy <u>*each*</u> of the B units of the round's risky alternative. In other words, you have to state your maximum buying price of each of the B units. Such decisions take the following form:

Gain	*Probability*
H ECU	50%
L ECU	50%

You must buy B units of the above risky alternative.
What is the maximum price are you willing to pay for *each unit*?

The ECU needed for buying the predetermined B units of the risky alternative will be deducted from the M_{ini} ECU you have in the bank.

If you need more than M_{ini} ECU for carrying out a buy decision, you can borrow these extra ECU from the bank at a gross interest rate of 1.5. Suppose, for instance, that M_{ini} = 50 ECU, but you need 120 ECU for buying the B units specified by the buy decision. You can borrow 70 (= 120−50) ECU from the bank and then pay 105 (= 70×1.5) ECU back at the end of the round.

• *Sell decisions*

For the sell decisions, you must report the lowest amount of ECU for which you would be willing to sell <u>*each*</u> of the S units of the round's risky alternative. In other words, you have to state your minimum selling price of each of the S units. Such decisions take the following form:

Gain	*Probability*
H ECU	50%
L ECU	50%

You must sell S units of the above risky alternative.
What is your minimum selling price for *each unit*?

The ECU you get from selling the predetermined S units of the risky alternative will be automatically deposited in the bank and earn an gross interest rate of 1.5.

For each of your eight decisions, irrespective of whether they are buy or sell decisions, you must state an amount between **0.50** and **12.00** ECU (up to two digits after the decimal).

Your round payoff

Your payoff in each round will depend on your decisions and on two random choices made by the computer. More specifically, your round payoff is determined as follows.

After you have made all your eight decisions, the computer will randomly select one of your decisions as the "relevant decision".

If the relevant decision is a buy decision, the computer will randomly choose a number between 0.50 and 12.00 (with two digits after the decimal). You can think of this number as the price at which the experimenters would sell each unit of the risky alternative.

- If this random number (i.e., the price at which the experimenters would sell each unit of the risky alternative) is greater than the maximum amount of ECU you were willing to pay for each unit, you do not buy any units of the risky alternative.
- If this random number is smaller than or equal to the maximum amount of ECU you were willing to pay for each unit, you buy the B units specified in the relevant decision, and pay *for each unit* an amount of ECU equal to the random number (i.e., equal to the price at which the experimenters would sell each unit; not to the amount you stated!). So, if we refer to this random number as p_B, you pay $p_B \times B$.

If the relevant decision is a sell decision, the computer will again randomly choose a number between 0.50 and 12.00 (with two digits after the decimal). Now you can think of this number as the price at which the experimenters would buy each unit of the risky alternative.

- If this random number (i.e., the price at which the experimenters would buy each unit of the risky alternative) is smaller than the minimum amount of ECU you asked for each unit, you do not sell any units of the risky alternative.
- If this random number is greater than or equal to the minimum amount of ECU you asked for each unit, you sell the S units specified in the relevant decision, and collect *for each unit* an amount of ECU equal to the random number (i.e., equal to the price at which the experimenters would buy each unit; not to the amount you stated!). So, if we refer to this random number as p_S, you collect $p_S \times S$.

With this mechanism it is in your best interest to state the "true" amount of ECU for which you would be willing to buy or to sell each unit of the risky alternative under consideration. Not reporting your true willingness to pay (in the buy decisions) and your true willingness to ask (in the sell decisions) will not help you.

The ECU you have in the bank at the end of the round (M_{end}) will be multiplied by 1.5. The resulting amount will be paid to you if it is positive, and will be paid by you if it is negative. M_{end} differs from M_{ini} (your initial endowment of ECU) only if you carry out a transaction, i.e., if you buy the B units specified by a relevant "buy" decision or you sell the S units specified by a relevant "sell" decision.

The units of the risky alternative you have at the end (N_{end}) allow you to gain

- $N_{end} \times H$ ECU with 50% probability;
- $N_{end} \times L$ ECU with 50% probability.

N_{end} differs from N_{ini} (your initial units of the risky alternative) only if you carry out a transaction.

To sum up, the following outcomes are possible.

- The relevant buy or sell decision does not result in any transaction. In this case, $M_{end} = M_{ini}$ and $N_{end} = N_{ini}$. Therefore

$$\text{your round payoff} = \begin{cases} M_{ini} \times 1.5 \quad + \quad N_{ini} \times H & \text{with 50\% probability,} \\ M_{ini} \times 1.5 \quad + \quad N_{ini} \times L & \text{with 50\% probability.} \end{cases}$$

- The relevant decision is a buy decision and you buy the B units of the risky alternative at a price equal to the random number p_B. In this case, $M_{end} = M_{ini} - p_B B$ and $N_{end} = N_{ini} + B$. Therefore

$$\text{your round payoff} = \begin{cases} (M_{ini} - p_B B) \times 1.5 \quad + \quad (N_{ini} + B) \times H & \text{with 50\% probability,} \\ (M_{ini} - p_B B) \times 1.5 \quad + \quad (N_{ini} + B) \times L & \text{with 50\% probability.} \end{cases}$$

- The relevant decision is a sell decision and you sell the S units of the risky alternative at a price equal to the random number p_S. In this case, $M_{end} = M_{ini} + p_S S$ and $N_{end} = N_{ini} - S$. Therefore

$$\text{your round payoff} = \begin{cases} (M_{ini} + p_s S) \times 1.5 \quad + \quad (N_{ini} - S) \times H & \text{with 50\% probability,} \\ (M_{ini} + p_s S) \times 1.5 \quad + \quad (N_{ini} - S) \times L & \text{with 50\% probability.} \end{cases}$$

At the end of each round, the computer will determine whether each unit of the risky alternative pays H or L ECU out.

The following examples should help you better understand the calculation of your round payoff.

Example 1
Suppose that you are endowed with $M_{ini} = 10$ ECU and $N_{ini} = 12$ units of a risky alternative, each unit of which allows you to gain either 8 or 4 ECU with 50% probability each. Suppose also that the randomly selected relevant decision is a buy decision in which you are asked to buy $B = 4$ units of the above risky alternative. Suppose finally that you report a maximum buying price of 6.45 ECU, and that the outcome of the risky alternative is 8 ECU.

- If the random number chosen by the computer is $p_B = 7$, you do not buy any units of the risky alternative (because $7 > 6.45$). This implies that you have (i) 10 ECU in the bank, from which you obtain $(10 \times 1.5) = 15$ ECU; (ii) 12 units of the risky alternative, from which you gain $(12 \times 8) = 96$ ECU. Your round payoff is therefore $15 + 96 = 111$ ECU.
- If the random number chosen by the computer is $p_B = 5.75$, you buy the 4 units of the risky alternative (because $5.75 < 6.45$) at the price of 5.75. This implies that you now have: (i) $10 - (5.75 \times 4) = -13$ ECU in the bank, i.e. you must pay $-13 \times 1.5 = -19.5$ ECU; (ii) $12 + 4 = 16$ units of the risky alternative, from which you gain $(16 \times 8) = 128$ ECU. Your round payoff is therefore $-19.5 + 128 = 108.5$ ECU.

Example 2
Suppose that you are endowed with $M_{ini} = 20$ ECU and $N_{ini} = 12$ units of a risky alternative, each unit of which allows you to gain either 10 or 5 ECU with 50% probability each. Suppose now that the randomly selected relevant decision is a sell decision in which you are asked to sell $S = 2$ units of the above risky alternative. Suppose finally that you report a minimum selling price of 5.25 ECU, and that the outcome of the risky alternative is 5 ECU.

- If the random number chosen by the computer is $p_S = 8.50$, you sell the 2 units of the risky alternative (because $8.50 > 5.25$). This implies that you have: (i) $20 + (8.50 \times 2) = 37$ ECU in the bank, from which you obtain $37 \times 1.5 = 55.5$ ECU; (ii) $12 - 2 = 10$ units of the risky alternative, from which you gain $(10 \times 5) = 50$ ECU. Your round payoff is therefore $55.5 + 50 = 105.5$ ECU.

The information you receive at the end of each round

At the end of each period, you will receive information about 1) the decision chosen by the computer as the relevant decision, 2) the random number selected by the computer, 3) whether or not you carry out the transaction corresponding to the relevant decision, 4) the outcome of the risky alternative, and 5) your corresponding round payoff.

Your final payoff

At the end of the experiment, one experimenter will randomly select one participant by drawing a ball from an urn that contains as many balls as the number of participants. This participant will in his turn randomly select one of the eight rounds of the experiment by drawing a ball from an urn containing eight balls numbered 1 to 8. This round payoff will be converted to euros (at the exchange rate of 10 ECU = 1 Euro) and paid out in cash.

In case of a negative payoff, losses up to €2.50 (= 25 ECUs) will be covered by your show-up fee. There are two alternatives concerning losses in excess of €2.50. The first is to pay the difference from your own money. The second is to pay the difference by performing (before leaving the lab) a task which consists of counting the occurrences of a specific letter in a lengthy text. You will be compensated with €1.00 for each correctly counted sentence. The drill is introduced to allow you to repay your losses; there is no way of earning extra money from it.

Before starting you will have to answer some control questions which will ensure your understanding of the rules of the experiment. Once everybody has answered all questions correctly, two practice rounds will help you familiarize yourself with the dynamics of the experiment. The result of these rounds will <u>not</u> be relevant to your final payoff.

Please remain quietly seated during the whole experiment. If you have any questions, please raise your hand now. Please click "ok" on your computer screen when you have finished reading the instructions of this part of the experiment.