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by

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Testing the Modigliani-Miller theorem directly in the lab: a general equilibrium approach

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Abstract

In this paper, we experimentally test the Modigliani-Miller theorem. Applying a general equilibrium approach and not allowing for arbitrage among firms with different capital structure, we are able to address a question fundamental to the valuation of firms: does capital structure affect the value of the firm? If so, how? We find that, consistent with the Modigliani-Miller theorem, experimental subjects well recognized the increased systematic risk of the equity with increasing leverage and accordingly demanded higher rate of return. Yet, this adjustment was not perfect: subjects underestimated the systematic risk of low leveraged equity whereas overestimated the systematic risk of high leveraged equity, resulting in a U shape weighted average cost of capital.

JEL Classification: G32, C91, G12, D53,

Keywords: The Modigliani-Miller Theorem, Experimental Study, Decision Making under Uncertainty, General Equilibrium

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1 Introduction

Ever since the appearance of Modigliani and Miller (1958) (commonly known as ‘MM’ theorem), there has been substantial effort in testing the Modigliani-Miller theorem. There has been enormous evidence supporting as well as refuting the propositions. The 1958 paper Modigliani and Miller (1958) itself had a section devoted to testing the propositions on oil and electricity utility industry and found little association between leverage and cost of capital. Later in Miller and Modiglian (1966), they performed a test using a two-stage instrumental variable approach on electric utility industry in the United States and found no evidence for “sizeable leverage or dividend effects of the kind assumed in much of the traditional literature of finance”. Davenport (1971) uses British data on three industry groups, chemicals, food and metal manufacturing, and finds that the overall cost of capital is independent of the capital structure. The opposition to the MM theorems came from many angles. Weston (1963) in a cross sectional study on electric utilities and oil companies finds that firm’s value increases with leverage. Robichek et al. (1967) find results consistent with a gain from leverage. Masulis (1980), Pinegar and Lease (1986), and Lee (1987) also find similar results. After thirty years of debate and testing, Miller (1988) conceded: “Our hopes of settling the empirical issues . . ., however, have largely been disappointed.” This is the fiftieth year of the paper and still the opinion may hold true.

After the 80s the direct testing of the Modigliani-Miller theorem using field data seems to have been given less focus, or simply forgotten. This is quite understandable given the unfruitful debate so far, and that a clean testing of the theorem using real market data is basically impossible due to the restrictions and assumptions that the theorem demands. Firstly, capital structure is difficult to measure. An accurate market estimate of publicly held debt is already difficult and to get a good market value data on privately held debt is almost impossible. The complex liability structure that firms face complicates this matter further, e.g., pension liabilities, deferred compensation to management and employees, and contingent securities such as warrants, convertible debt, and convertible preferred stock. Secondly, it is nearly impossible to effectively disentangle the impact of capital structure on the value of firms from the effects of other fundamental changes. Myers (2001) therefore rightly admits, “the Modigliani and Miller (1958) paper is exceptionally difficult to test directly”.

In this paper, we reopen the issue and test the Modigliani-Miller theorem directly via a laboratory experiment. Compared to field works, laboratory studies offer more control. Changes of firms’ other aspects can be minimized while the capital structure of firms are adjusted, and the capital structure of the firm can be easily measured. By constructing a

testing environment as close as possible to the theoretical model, we want to see whether, nonetheless, experimental subjects value firms differently. We adapted our experiment model from the theoretical model of (Stiglitz, 1969). Using a general equilibrium approach, we are able to show that, when individuals can borrow at the same market rate of interest as firms and there is no bankruptcy, the Modigliani-Miller theorem always holds in equilibrium, and that this result does not depend on individuals' risk attitudes and initial wealth positions.

The remainder of the paper is organized as follows. In section 2, we first discuss the U shape weighted average cost of capital approach and demonstrate its defective link. Then we introduce the Modigliani-Miller theorem and a theoretical model for the experiment basing on Stiglitz (1969). In section 3 the experimental design is presented. Results are reported in section 4 and 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: equity is risky and thus more costly, while debt is not or at least much less risky¹. Therefore a firm can reduce its cost of capital by issuing some debt in exchange for some of its equity. As the debt equity ratio increases further, default risk becomes large and after some point debt becomes more expensive than equity.

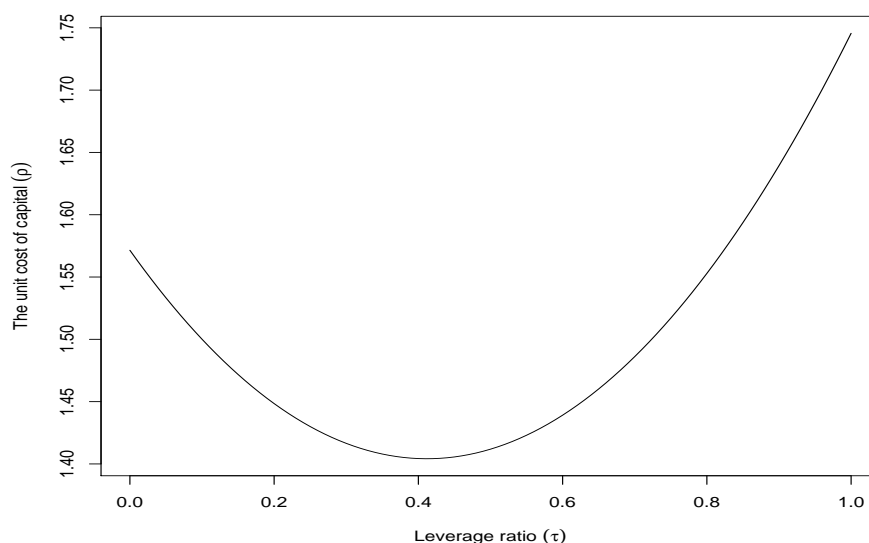
To make it clearer, let us consider a firm with a market value of debts B , and a market value of shares S . Let $\tau = \frac{B}{V}$ denote the leverage ratio, i denote the expected rate of return on equity, and r the rate of return on debts. Then the unit cost of capital, ρ , is simply the weighted average of i and r :

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

In the U shape of the cost of capital approach, it is assumed that i is independent of τ , whereas r is a function of τ . More specifically, $r < i$ when τ is small and $r > i$ when τ

¹A firm promises to make contractual payments no matter what the earnings are. Thus there can exist no risk when there is no bankruptcy possibility. When there is bankruptcy possibility, since debt has priority over equity in payment, it is still the less risky one

exceeds some threshold. This implies U shape of firms' cost of capital, as shown by the following figure.



However, a careful examination of (1) reveals a defective link between ρ and τ : the U shape of firms' cost of capital is true only if i is not influenced by τ , which, as will be demonstrated below, does not hold as long as investors are risk averse.

Consider the following simple numerical example. A firm generates income \tilde{X} in time 1 (before interest payment), which for simplicity is assumed to take only two possible values, 200 and 60, with equal probability, and hence the expected value, $\bar{X} = 130$. In the first scenario let us consider that the firm is only financed by equity ($V = S = 100$). Then the rate of return on equity has the following structure:

Rate of return on equity	Prob.	
2.0	0.5	(2)
0.6	0.5,	

and the expected rate of return on equity (i) would be 1.3. Suppose now the firm issued bonds (B') worth 50 at an interest rate (r) of 1.1. By assumption, i remains unchanged. Let V' denote the value of the new firm and S' denote its value of equity, by (1),

$$\rho = \frac{130}{V'} = 1.3 \frac{V' - 50}{V'} + 1.1 \frac{50}{V'}, \quad (3)$$

which implies $V' \approx 108$, and thus $S' \approx 58$. The rate of return on equity is then:

Rate of return on equity	Prob.	\approx	Rate of return on equity	Prob.	(4)
$\frac{200-50 \times 1.1}{58}$	0.5		2.5	0.5	
$\frac{60-50 \times 1.1}{58}$	0.5		0.1	0.5.	

Notice that, investors ask for the same rate of return for a income flow with higher risk. As suggested by standard financial theory, this can not happen as long as investors are risk averse.

In fact, above example has already revealed the intuition of the Modigliani-Miller theorem (hereafter the MM theorem). Recognizing the relationship between τ and i , Proposition I of Modigliani and Miller (1958) argues 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

In examining the Modigliani-Miller theorem, there are several approaches that might be taken. A natural approach is to take the Modigliani and Miller (1958) model where arbitrage among firms are possible. But, in this paper, we shall take a rather different approach. We ask experimental subjects to evaluate the equity of firms with different capital structure separately in different markets, one firm in each market. No arbitrage among these firms is possible.

Arbitrage process plays an important role in Modigliani and Miller (1958); it helps to restore the Modigliani-Miller theorem once it is violated. But, as shown by Hirshleifer (1966) and Stiglitz (1969), arbitrage is not necessary for The Modigliani-Miller theorem to hold. Moreover, allowing for arbitrage among firms may exclude one potentially interesting phenomena: suppose there are systematic preferences for firms with particular capital structure, this ‘anomaly’ would not be observed on the market level since it would be eliminated away by a few arbitragers, and it would have been interesting if we can observe this anomaly and understand why it occurs. After all, as demonstrated by Shleifer and Vishny (1997), arbitrage can never be complete in real financial markets. Thus, by excluding arbitrage among firms it allows us to address a question fundamental to the valuation of firms: *Do subjects systematically evaluate firms with different capital structure differently? If so, how?*

There is an additional strength in proceeding this way. Some empirical studies show that firms with different capital structures are valued similarly. However, this does not necessarily imply the irrelevance of capital structure to the valuation of the firm. It could be that, although investors in general preferred some capital structures τ^* to some other capital structures τ' , these preferences would not be revealed on the market level since firms - recognizing investors' preferences - would adjust their capital structure towards τ^* . As a result, firms are valued similarly, but concentrated on some capital structures τ^* . Our approach would allow us also to address this possibility.

Not allowing for arbitrage among firms, however, does cause one potential serious problem: the law of one price can not be applied any more. The law of one price states that the same goods must sell at the same price in the same market. Our experimental design effectively cuts the link among firms, and make the markets for different firms independent from each other. It is then difficult to guarantee that the market conditions, including market rules and traits of market participants, are the same for different firms. This could seriously blur the message of experimental results. For example, the same lottery ticket is usually valued differently by millionaires and poor people, but this difference reflects not the difference of lottery tickets but the heterogeneity of market participants. More specifically, differences in the values of the firms in the economy not allowing for arbitrage among firms with different capital structures could be due to two possibilities:

1. market participants apply a valuation process by which firms with different capital structures are valued differently, or
2. participants with certain traits have inherent preferences for equity with a particular income pattern, e.g., due to portfolio diversification reason.

The second possibility is especially relevant in the current setting since experimental subjects are mainly students and they share similar financial backgrounds. Without proper control, this problem of sample selection could significantly limit the validity of our results. Even if systematic differences in the values of the firms are found, it might not be relevant on market level; it might be a special case pertaining only to our subjects.

Since the first possibility will be our main focus, a proper model should minimize the second possibility. For this purpose, we base adapt the model of Stiglitz (1969). Stiglitz (1969) puts forward a general equilibrium model, and it can be shown that the Modigliani-Miller theorem holds regardless the initial wealth condition of market participants. Furthermore, the equilibrium solution in Stiglitz (1969) is derived by the state preference approach.

Comparing to the more familiar mean-variability approach, i.e. mean-variance approach, this approach does not make strong assumptions about risk attitudes or the shape of the utility function. Hence the results hold under more general conditions.

2.2 The Model

For simplicity consider an economy where there is one firm which exists for two periods: now (denoted by t_0) and future (denoted by t_1). The market values of firm's equity and debt are respectively S and B , and hence the market value of the firm is

$$V = B + S.$$

The uncertain income stream \tilde{X} generated by firm i at date t_1 is a function of the state $\theta \in \Theta$, and $\tilde{X}(\theta)$ denotes firm's income in state θ . There are n investors, and the set of investors is denoted by N . Each investor i is endowed with an initial wealth of ω_i , which is composed of a fraction α_i of equity S , and B_i unit of bonds. Since the economy is closed, we have

$$\sum_{i \in N} \alpha_i = 1, \quad \sum_{i \in N} B_i = B, \quad (5)$$

By convention, one unit of bond costs one unit of money, thus

$$\omega_i = \alpha_i S + B_i. \quad (6)$$

In addition, there exists a credit market, where both the firm and investors can borrow or lend at the rate of interest r . To be consistent with the assumptions of Modigliani-Miller theorem, we assume the firm never goes bankrupt. Investors prefer more to less. Moreover, all investors are assumed to 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 first prove the following proposition:

Proposition 1 *(1) If there exists a general equilibrium with the firm fully equity financed and having a particular value, then there exists another general equilibrium solution for the economy with the firm having any other capital structure but with the value of the firm*

remains unchanged. (2) Moreover, this holds in any equilibrium.²

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

Consider the first economy, since here the firm issues no bonds (B), we have $V_1 = S_1$, and $\sum_{i \in N} B_i^1 = 0$. Here a positive (negative) value of B_i^1 would mean that investor i invests (borrows) B_i^1 units of money in (from) the credit market. Let $Y_i^1(\theta)$ denote investor i 's income in state θ . With the portfolio of α_i shares and B_i^1 units of bonds, investor i 's return in state θ may be written as:

$$\begin{aligned} Y_i^1(\theta) &= \alpha_i \tilde{X}(\theta) + rB_i^1 \\ &= \alpha_i \tilde{X}(\theta) + r(\omega_i - \alpha_i V_1) \end{aligned} \tag{7}$$

which follows by $S_1 = V_1$ and (6).

Consider now the second economy where the firm issues bonds with a market value of B^2 . Let S_2 denote the value of the firm's equity in this economy, we have the value of the firm $V_2 = S_2 + B^2$ and $\sum_{i \in N} B_i^2 = B^2$. Notice that the firm generates the same pattern of income stream \tilde{X} . With a portfolio of α_i fraction of equity and B_i units of bonds, investor i 's return in state θ is then given by:

$$\begin{aligned} Y_i^2(\theta) &= \alpha_i(\tilde{X}(\theta) - rB^2) + rB_i^2 \\ &= \alpha_i(\tilde{X}(\theta) - rB^2) + r(\omega_i - \alpha_i S_2) \\ &= \alpha_i \tilde{X}(\theta) + r(\omega_i - \alpha_i V_2), \end{aligned} \tag{8}$$

where the third equality follows by $S_2 = V_2 - B^2$.

If $V_1 = V_2 = V^*$, the opportunity sets of individual i in both economies, $Y_i^1(\theta)$ and $Y_i^2(\theta)$, will be identical:

$$Y_i^1(\theta) = Y_i^2(\theta) \text{ for } \forall \theta \in \Theta. \tag{9}$$

²Stiglitz (1969) only proves the first part of proposition 1. We complete the following proposition by demonstrating the second part of proposition 1.

If the vector $(\{\alpha_i^*\}_{i \in I})$ maximizes individual'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 $V_1 = V_2 = V^*$ must hold in any equilibrium when agents are strictly risk averse.

Suppose there exists an equilibrium in the second economy where $V_2' > V_1 = V^*$. This in turn implies $S_2' = V_2' - B^2 > V^* - B^2 = S_2^*$. Notice that equity's rate of return is calculated as $\frac{\tilde{X} - rB}{S}$, with \tilde{X} and B remaining unchanged, the increase of equity value from S_2^* to S_2' decreases equity's rate of return. However, given any risk composition of the second economy, the decrease of equity's rate of return discourages the demand for equity. Since the equity market of the second economy clears at $S_2^* = V^* - B^2$, it follows then there will be over supply of equity when $S_2' > S_2^*$. A contradiction to $V_2' > V^*$ being an equilibrium. The other case $V_2' < V^*$ can be proven similarly.

Several features of the model are worth noticing. Firstly, no assumptions on investors' initial wealth position are made, which is particularly helpful when conducting laboratory experiments because it reduces effects of sample selection on results. Secondly, except for the basic assumption that investors prefer more to less, no strong assumption about the shape of investors' utility function are made. This is also very appealing since measuring subjects' risk attitudes are tricky and inaccurate. Therefore, we expect experimental results based upon the above model to hold in broad circumstances.

3 Experimental Protocol

The computerized experiment was conducted in September 2007. Overall, we ran 2 sessions with a total of 64 subjects, all being students at the University of Jena. The two sessions were run in the computer lab of the Max Planck Institute of Economics in Jena (Germany). The experiment was programmed using the Z-Tree software (Fischbacher, 1999). Considering the complexity of experimental procedure, only students with relatively high analytical skills were invited, e.g., students majoring in mathematics, economics, business administration, or physics.

3.1 General Environments and Procedures

Each experimental session consists of two subsequent phases. In the first phase, subjects' risk attitudes are measured using table 4 (Holt and Laury, 2002). In table 4, each row denotes one choice situation. In each choice situation, option Y pays out 50 ECU (Experi-

mental Currency Unit) with certainty, and 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 choice situations, their probabilities vary. Subjects are asked to choose between X and Y for each of ten choice situations. After they make their decisions, one of the 10 choice situations is randomly chosen. Subjects' experimental earnings depend on their choices in the chosen situation. However, in order not to affect subjects' risk attitudes in the following phase, experimental earnings for the first phase are not announced yet. They are announced at the end of the whole experiment, together with their earnings in the second phase of the experiment.

In the second phase, subjects are divided into 4 independent groups, with 8 subjects each. Group compositions are kept constant through out this phase. The second phase of experiment consists of 8 treatments (in the experiment, treatments are referred as rounds) i.e., we compare treatments within subjects.

The experimental environments in each treatment are constructed as close as possible to the theoretical model. Firms are represented by a risky asset generating income flow:

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

For simplicity, we impose

$$Prob(\theta = \text{good}) = Prob(\theta = \text{bad}) = \frac{1}{2}.$$

Firms have 100 shares outstanding and differ only in the market value of debts B . Since there is no bankruptcy possibility, bonds are perfectly safe, and one unit of money invested in bonds yielded a gross return of 1.5, that is, the net risk-free interest rate is 0.5. Subjects are told they can borrow any amount of money from a bank at this interest rate.

In each treatment, only one firm is evaluated through a market mechanism (to be explained shortly), hence valuation of firms are independent from treatment to treatment: subjects' decisions in one treatment do not affect their play in other treatments. To further discourage (potential) portfolio effects, only one treatment is randomly selected for experimental payment. The sequence that firms are evaluated across 8 treatments are characterized by the market value of bonds B :

<i>Treatments</i>	1	2	3	4	5	6	7	8
<i>Bond value</i>	50	⇒ 350	⇒ 100	⇒ 0	⇒ 400	⇒ 200	⇒ 500	⇒ 300,

where the first two treatments are for training, and the last 6 are formal treatments. However, in the experiment, subjects are not presented with above structures. Instead, they are asked to evaluate the resulting equities of firms after the interest payment of debt has been deducted:

$$\begin{aligned}
 & 1 \left\{ \begin{array}{ll} \textit{Gain} & \textit{Prob.} \\ 11.25 & 0.5 \\ 7.25 & 0.5 \end{array} \right. \implies 2 \left\{ \begin{array}{ll} \textit{Gain} & \textit{Prob.} \\ 6.75 & 0.5 \\ 2.75 & 0.5 \end{array} \right. \implies 3 \left\{ \begin{array}{ll} \textit{Gain} & \textit{Prob.} \\ 10.50 & 0.5 \\ 6.50 & 0.5 \end{array} \right. \implies \\
 & 4 \left\{ \begin{array}{ll} \textit{Gain} & \textit{Prob.} \\ 12.00 & 0.5 \\ 8.00 & 0.5 \end{array} \right. \implies 5 \left\{ \begin{array}{ll} \textit{Gain} & \textit{Prob.} \\ 6.00 & 0.5 \\ 2.00 & 0.5 \end{array} \right. \implies 6 \left\{ \begin{array}{ll} \textit{Gain} & \textit{Prob.} \\ 9.00 & 0.5 \\ 5.00 & 0.5 \end{array} \right. \implies \\
 & 7 \left\{ \begin{array}{ll} \textit{Gain} & \textit{Prob.} \\ 4.50 & 0.5 \\ 0.50 & 0.5 \end{array} \right. \implies 8 \left\{ \begin{array}{ll} \textit{Gain} & \textit{Prob.} \\ 7.50 & 0.5 \\ 3.50 & 0.5 \end{array} \right. \tag{10}
 \end{aligned}$$

Here the concern is that some of the subjects may have learned the Modigliani-Miller theorem in the past, and with complete capital structure (firms' income flow and the market value of bond), they may try to be consistent with the Modigliani-Miller theorem and thereby bias the results. Presenting them only with the resulting equities should significantly increase their difficulty in doing so.

More specifically, the experimental procedure in each treatment follows thus:

1. At the beginning of each treatment, subjects are presented with a risky alternative: one of the resulting equity of a firm shown in (10). In addition, they receive some initial endowments.
2. A market mechanism becomes available, with which subjects in each group can trade the risky alternative with each other. Trading quantity can only be of integers and short selling is not allowed. Notice that the highest possible value of a unit of equity is $(1200-B)/100$, and the lowest possible value of a unit of equity is $(800-B)/(100 \times 1.5)$, buying or selling prices are restricted to the range of $[(1200-B)/100, (800-B)/(100 \times 1.5)]$.
3. After some time, the market closes. When subjects have a net change in share holding after the market process, the agent should either (a) pay a per-unit price equal to the market-clearing price for each unit of equity he purchased, which is automatically deducted from the money in their bank account, or (b) receive a per-unit price equal to the market-clearing price for each unit he sold, which is automatically deposited into the bank and earn a risk-free interest rate of 0.5. Subjects then receive the following information:
 - the market clearing price;
 - own final holding of equity α_i and bonds B_i .

Notice that the information about the realized state are not given here. This is to decrease income or wealth effects. Instead, this information is given at the end of the this phase³.

The feedback information subjects receive at the end of this phase is: (1) the state of world realized for each treatment; (2) own net profit in each treatment; (3) the randomly chosen treatment for payment; (4) own final experimental earning.

To provide subjects with stronger marginal incentive and increase the cost of making mistakes so that subjects take decisions more seriously, we grant subjects an initial endowment as risk free credit and pay them only the net profits they make. We now describe the structure of this initial endowment and explain in detail the trading mechanism.

3.2 Initial Endowments and the Trading Mechanism

The determination of subjects' initial endowments is important, especially when subjects' payments are determined by the net profits they make. Since, as the theoretical model suggests, subjects' endowments in different treatments should be the same, a natural choice is to endow subjects with some amount of money. However, this is impossible here because, as a general equilibrium model, this requires to know the value of the firm before the experiment.

Taking into account above considerations, subjects' initial endowments in each treatment are implemented in the following way: among the 8 subjects of each group, four subjects are endowed with $12\% \times 100$ shares and $12\% \times B$ units of money, and the remaining four subjects are endowed with $13\% \times 100$ shares and $13\% \times B$ units of money. Subjects' money endowments are automatically deposited into a bank. For each unit of money deposited/borrowed the bank offers/charges 1.5 at the end of the treatment, implying a net risk-free interest rate of 0.5.

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

³We did provide this information in the two training treatments, since there this problem did not exist and giving feedback about payments should increase learning.

In security markets, the opening price of a stock in a new trading day is especially difficult to determine because of the high uncertainty regarding a stock's fundamental value following the overnight or weekend nontrading period. To produce a reliable opening price, most major stock exchanges, e.g., New Stock Exchange, London Stock Exchange, Frankfurt Stock Exchange, Paris Bourse, use call auction to open markets. Economides and Schwartz (1995) show that, by gathering many orders together, call auction can facilitate order entry, reduce volatility, and enhance price discovery. These features of call auction make it a perfect candidate for our experimental trading mechanism.

In the experiment, the call auction operates in the following manner. When call auction becomes available in each treatment, participants are told they had 3 minutes to submit buy or sell orders. In the buy or sell orders, they must specify the number of shares and the price at which they wish to purchase (or sell). At the end of 3 minutes, an aggregate demand schedule and supply schedule will be constructed from the individual orders, and the market-clearing price is chosen to maximize trades. While this concept is clear, its implementation is tricky and thus deserves some further remark. In the experiment, we use the following algorithm to computer the market clearing price:

1. Any buy order with price P_b and quantity Q are transformed into a vector (P_b, P_b, \dots, P_b) with length Q . Each element of this vector can then be treated as an unit buy order at price P_b . These vectors are then combined to build one general buy vector, which is then sorted by buying price from high to low. Similar operation is done for all sell orders except that the resulted vector is sorted by selling price from low to high. By this, a aggregate demand schedule and supply schedule are constructed:

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

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), 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

$$\max\{P_s^{i-1}, P_b^i\} < P^* < \min\{P_b^{i-1}, P_s^i\}. \quad (11)$$

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, then 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 $P_b^{end} > P_s^{end}$.

In order to increase learning and help subjects to set “reasonable price”, the 3 minutes are divided into three trading periods, each lasts for 1 minute⁴. After each of the first two trading periods, an indicative market clearing price using above algorithm is published. The indicative market price suggests that if no one change their orders till the end of 3 minutes, all eligible orders will be executed at this price. Subjects are also told that they can always revise their orders before the end of 3 minutes.

4 Results

In reporting our results, we proceed as follows. First, we present an overview of elicited risk attitudes, trading results, and firms’ values across periods. Then, we turn to our main hypothesis and investigate whether capital structure affects the value of the firm, and if so, how?

4.1 General Results

Risk attitudes play an important role in the current experiment. In fact, the only rational reason for trading in each group is the heterogeneity of risk attitudes. Notice in table 4, a relatively more risk averse subjects choose more often the sure outcome (Y), whereas a relatively less risk averse subject choose more often the risky outcome. Thus we compute the times that the sure outcome is chosen by the subjects, and treat them as the proxy for risk attitudes. Let γ denote this proxy. Obviously, a larger γ implies relatively higher degree of risk aversion. Though rational agents do not choose the sure outcome in one row, switch to the risky alternative in the next row, and then switch back in one of the following rows, this non-monotonicity of choices is allowed in the experiment. Fortunately

⁴To allow for sufficient learning, the call auction opened for 6 minutes in each of the two training treatments, 2 minutes for each trading periods.

this non-monotonicity of choices is not observed. This is probably due to our stringent subjects selection criteria. The median of γ is 6, indicating subjects are mostly risk averse.

Standard portfolio theory suggests that relatively risk averse subjects prefer to keep their wealth more as safe deposits, whereas less risk averse subjects are more tolerant to risky alternatives. We found that the correlation between γ and subjects' money in the bank is significantly positive (Spearman's $\rho = 0.09$, with p-value less than 0.01), and the correlation between γ and subjects' holding of risky alternative is significantly negative (Spearman's $\rho = 0.091$, with p-value equal to 0.05). This result is consistent with the above observation.

As indicated above, due to the complexity of our experiment, only subjects with relatively high analytical skill are invited. Moreover, a set of control questions is given the subjects to make sure they well understand the experiment. Nevertheless, it is likely that subjects do not understand the experiment and hence results are not reliable. Indeed, we found in the post-experimental questionnaire that a number of subjects complained about the complexity of the setup. It is then important to examine whether the experimental results are reliable. This can be checked by comparing the experimental values of firms with the market value of the firm resulting from rational risk neutral agents. Since the risk free net interest rate is 0.5, a return structure of 1200 or 800 with equal probability of 0.5 should be valued at 667 by risk neutral rational agents. Figure 1 reports the general development of firms' value across periods, where y-axis denotes the experimental market value of firms (equity plus bond), and x-axis denotes experimental periods. Every three consecutive periods consist of one treatment, i.e., 1-3, 4-6, etc. Empty circles denote firms' indicative values, calculated by indicative market clearing prices produced in the first two trading periods of each treatment. Triangles denote firms' final values, calculated by the final market clearing prices produced in the last trading periods of each treatment.

When all these points are considered, the median value of firms is 700, and they are not significantly different from 667 (two sided Wilcoxon rank sum test with p-value of 0.83). When only triangles are considered, the median value of firms becomes 677.5, and they are not statistically different from 667 (two sided Wilcoxon rank sum test with p-value of 0.79). When the first two treatments are taken out and only the final market clearing prices of the remaining 6 treatments are considered, median of firms' values becomes 667.5. Therefore, in spite of the complexity of the experimental procedure and the difficulty of the task, subjects performed surprisingly well, and the results were reasonable.

Above results suggest that empty circles are much more volatile than triangles. This is because the indicative prices produced in the first two trading periods were usually not

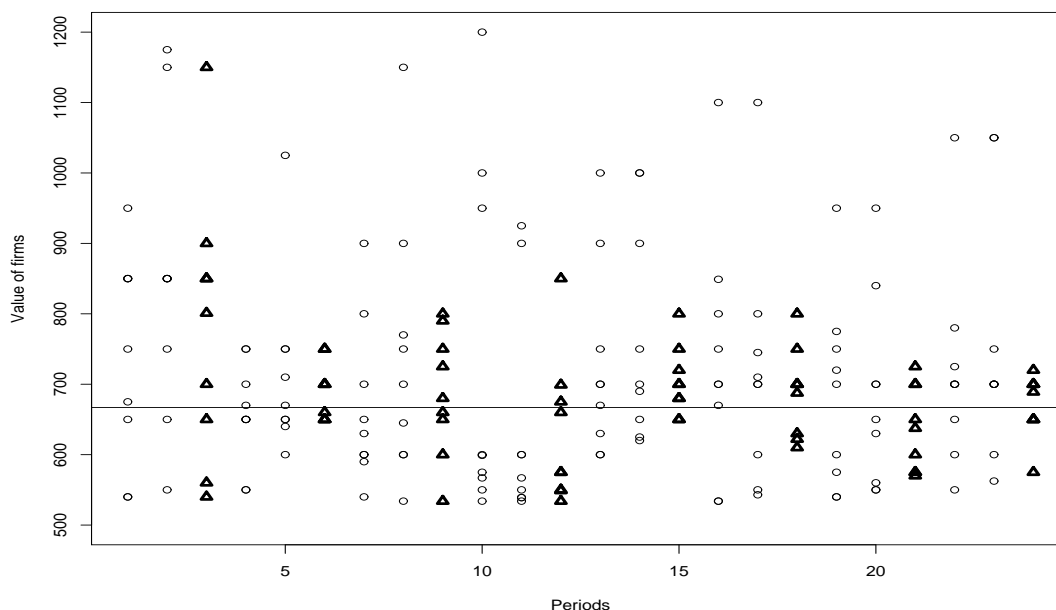


Figure 1: Values of firms across periods

mature yet. Moreover, since these prices were not real market clearing prices, subjects might not submit their formal orders during this time, rather, they might either take this opportunity to understand the market mechanism or to enter deceptive orders in the hope of fooling others.

Indeed, it seems there are two levels of learning happening in this phase of the experiment. The first level of learning occurs within each treatment. This is confirmed when comparing indicative prices with final market clearing prices (respectively empty circles and triangles in figure 1). It is found that the mean of firms' values is closer to 667 when only final market prices are considered (the mean of firms' values based on indicative prices is 715.90; whereas the mean of firms' values based on final market clearing prices is 692.55). We also performed a non-parametric variance ratio test (Gibbons and Chakraborti, 1993) to compare the variance of indicative prices and final market clearing prices. We find that indicative prices are significantly more volatile than final market clearing prices (one sided rank based Ansari-Bradley two sample test, $p < 0.01$), possibly a result of learning.

In order to examine the second level of learning: learning across periods, the development of firms' values across periods is examined. Before presenting the statistic model and results, however, an additional feature of the experiment needs to be considered. In the

Table 1: Regression results

Regressions	Variable	Coefficient	Std. Error	t-statistic	p-value
All treatments	v	735.9663**	25.8236	28.4997	0.0000
	t	-3.7310*	1.5191	-2.4562	0.0169
Last 7 treatments	v	690.4385**	23.6855	29.1502	0.0000
	t	-1.2017	1.3008	-0.9238	0.3598

** Significant at $p = 0.01$, * Significant at $p = 0.05$.

experiment, firms are valued independently within groups, thus firms' values critically depend on groups' composition of risk attitudes. A group with relatively less risk averse subjects tends to evaluate a firm higher than a group with relatively more risk averse subjects, and this difference can be significant. Indeed, the standard deviation of the means of groups' firms' values is as large as 47.08. Hence, a good statistic model should take group heterogeneity into account and have proper control of it. For this purpose, we run a linear regression with mixed effects⁵ based only on final market clearing prices, where the dependent variable is firms' values, independent variables are intercept and period (t), and random effects that vary across 9 groups are the intercept. Since, as suggested above, subjects' behaviors in the first treatment are very volatile, a similar regression is run based only on the last 7 treatments. Formally, the model is as follows:

$$V_i = v + u_i + \alpha \cdot t + \varepsilon_i, \tag{12}$$

where $i \in \{1, 2, \dots, 9\}$ denotes the 9 independent groups, $u_i \sim N(0, \sigma_u^2)$ denotes the random effects in the intercept for each group, and $\varepsilon_i \sim N(0, \sigma_\varepsilon^2)$. Results of regression are presented in table 1.

When all treatments are considered, the coefficient for period turns out to be weakly significant (-3.7310 with $p < 0.05$), indicating that firms' values decrease across periods and approach to 667. However, when only the last 7 treatments are considered, this coefficient is not significant anymore, indicating that learning mainly occurs in the first treatment. Since we are mainly interested in the equilibrium behavior, this result suggests that, due to learning and non-binding of indicative prices, indicative prices in the first two trading periods of each treatment are not mature yet, and the final market clearing prices in the first treatment are too volatile to be used. Therefore, following statistical analysis will mainly rely on final market clearing prices of the last 7 treatments, unless explicitly stated otherwise.

⁵See Jose C. Pinheiro (1993) for a good reference of mixed effects models.

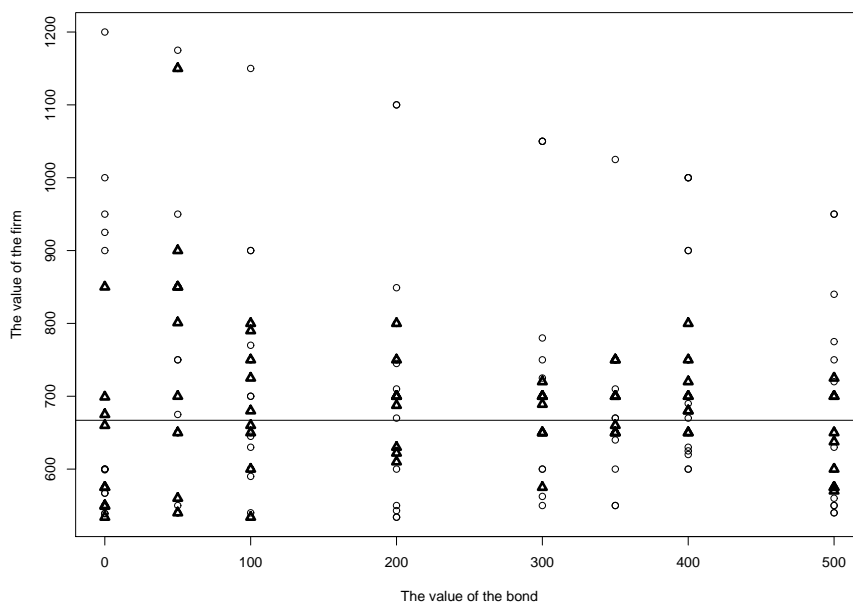


Figure 2: Firms' value conditional on the market value of bonds

4.2 The main hypothesis

We now turn to our main hypothesis: does capital structure affect the value of the firm, and if so, how?

In the theory of the cost of capital, there are mainly two competing ones: the Modigliani-Miller theorem and the U shape cost of capital. The Modigliani-Miller theorem states that the value of the firm is independent of the capital structure; whereas the U shape cost of capital implies that the cost of capital first decreases with the value of bond, and then increases after the ratio of bonds exceeds some threshold. In the following, we shall compare these two theories and see which best organizes data.

Figure 2 reports the value of the firm as a function of the value of bond for all 9 groups. All prices are used in order to give a general picture.

As before, empty circles denote values of firms based on indicative prices, and triangles denote values of firms based on final market clearing prices. The horizontal line is $V = 667$, the value of firms implied by risk neutral rational agents. Visually, it seems the horizontal line captures data quite well.

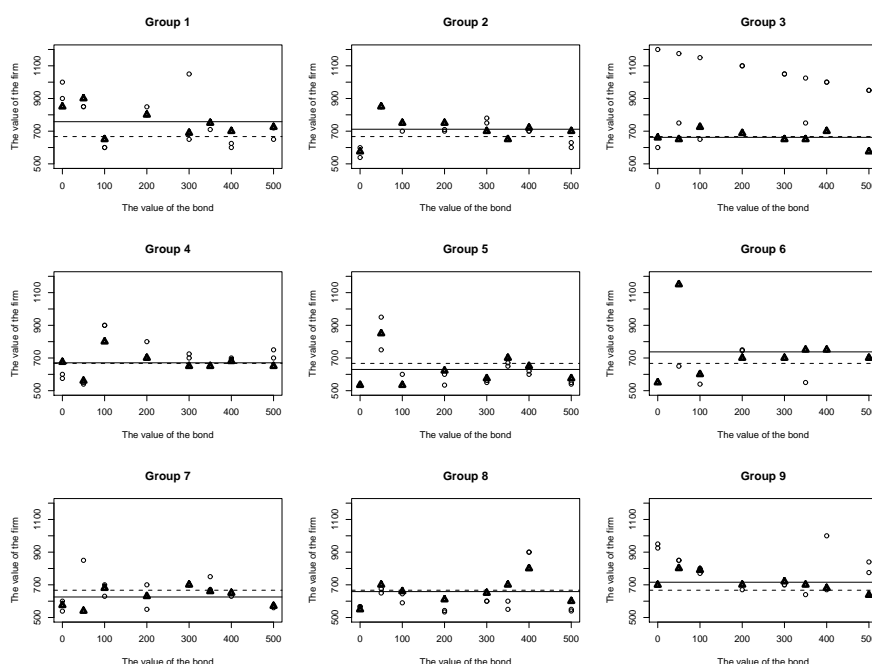


Figure 3: The value of the firm conditional on the value of the bond for the 9 groups

As mentioned above, group heterogeneities might blur the picture, in figure 3, we report the same relationship for each group. Here, the horizontal real line denotes the group mean of firms' values when only final market clearing prices are considered, and the horizontal virtual line is $V = 667$.

The Modigliani-Miller theorem suggests that the increase of leverage increases the systematic risk of equity. How well did our experimental subjects recognize the change of systematic risk due to the change of the capital structure? For this purpose, we compute the correlation between the value of the equity and the value of bond. This correlation is negative and close to -1 (Spearman's $\rho = -0.9313$, $p < 0.01$. First treatment is excluded, and only the final market clearing prices are considered). Thus, it seems the change of systematic risk could be almost perfectly recognized, a result consistent with the Modigliani-Miller theorem.

To examine the relationship between the value of the firm and the value of the bond more precisely, we run a linear regression with mixed effects. The first treatment are excluded and only the final market clearing prices are used. Explanatory variables are the intercept (v), the value of bond (B), the square of the value of bond (B^2), and period (t). Random

Table 2: Regression results

Expl. Variable	Coefficient	Std. Error	t-statistic	p-value
v	654.1631**	25.566248	25.5870	0.0000
B	0.4846**	0.1568	3.0900	0.0032
B^2	-0.0009**	0.0003	-2.9071	0.0054
t	-1.6570	1.3129	-1.2621	0.2127
Std. dev. of the random effects		$\sigma_u = 33.8011$;		
Std. dev. of the error term		$\sigma_e = 57.9559$		

** Significant at $p = 0.01$.

effects are the 9 independent groups. Formally, the model is as follows:

$$V_i = v + u_i + \beta_1 \cdot B_i + \beta_2 \cdot B_i^2 + \beta_3 \cdot t + \varepsilon_i, \quad (13)$$

where $i \in \{1, 2, \dots, 9\}$ denotes the 9 independent groups, $u_i \sim N(0, \sigma_u^2)$ denotes the random effects in the intercept for each group, and $\varepsilon_i \sim N(0, \sigma_e^2)$. The results of the regression are presented in Table 2.

As we can see from tale 2, both coefficients for B and B^2 are statistically significant. Moreover, the signs of these two coefficients are consistent with the U shape cost of capital hypothesis. The coefficient for t is not significant, suggesting that, after excluding the first treatment, learning is not significant anymore.

Another way to look at data reveals similar information. We run a different regression model with mixed effects, where the dependent variable is weighted average cost of capital ($WACC$), calculated as the expected return of the firm (1000) divided by the market value of the firm, and independent variables are financial leverage (τ), measured as the ratio of market value of debt to the market value of the firm, τ^2 , and period (t). Formally, the model is:

$$WACC_i = \kappa + u_i + \beta_1 \cdot \tau_i + \beta_2 \cdot \tau_i^2 + \beta_3 \cdot t + \varepsilon_i, \quad (14)$$

where $i \in \{1, 2, \dots, 9\}$ denotes the 9 independent groups, $u_i \sim N(0, \sigma_u^2)$ denotes the random effects in the intercept for each group, and $\varepsilon_i \sim N(0, \sigma_e^2)$. The results of the regression are presented in Table 3.

Both regressions are in favor of the U shape cost of capital theory. And based on above parameters, the weighted average cost of capital can be written as a function of leverage

Table 3: Regression results

Expl. Variable	Coefficient	Std. Error	t-statistic	p-value
κ	1.5715**	0.0552	28.4585	0.0000
τ	-0.8127**	0.1979	-4.1074	0.0001
τ^2	0.9868**	0.2380	4.1462	0.0001
t	0.0024	0.0029	0.8460	0.4015
Std. dev. of the random effects	$\sigma_u = 0.07429$;			
Std. dev. of the error term	$\sigma_e = 0.1255$;			
Number of observations	63			

** Significant at $p = 0.01$, * Significant at $p = 0.05$.

ratio:

$$WACC = 1.5715 - 0.8127 \cdot \tau + 0.9868 \cdot \tau^2. \quad (15)$$

Figure 4 reports and fitted values for regression 14 and the curve implied by equation (15).

5 Conclusion

When a firm's leverage increases, the systematic risk of the equity of the firm increases as well. Modigliani and Miller (1958) show that the increased rate of return required by equity holders exactly offsets the lower rate of return required by bonds, and as a result, the weighted average cost of capital remains the same. In this paper, we experimentally test the Modigliani-Miller theorem. Our experimental result suggests that subjects recognize the increased systematic risk of equity when leverage increases, and they ask for higher rate of return for bearing this risk. Yet, this adjustment is not perfect: they underestimate the systematic risk of low leveraged equity and overestimated the systematic risk of high leveraged equity, resulting in a U shape weighted average cost of capital.

However, we have to stress that we do not regard our results as definitive but merely as an indicative of a useful methodology, and that the evidence presented above suggests that the effect of capital structure to the cost of capital is not entirely clear and thus more study should be done. After all, as suggested in numerous research in behavioral economics (Kahneman and Tversky, 1984; Thaler, 1993), investors are far from being a perfect "Homo economist". Because of these "imperfections", it is unclear whether the

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