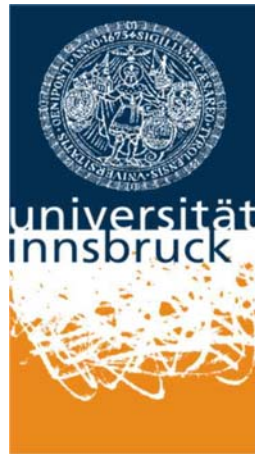


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in the lab: a general equilibrium approach**

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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 directly test the Modigliani-Miller theorem in the lab. Applying a general equilibrium approach and not allowing for arbitrage among firms with different capital structures, we are able to address this issue without making any assumptions about individuals' risk attitudes and initial wealth positions. We find that, consistent with the Modigliani-Miller theorem, experimental subjects well recognized the increased systematic risk of equity with increasing leverage and accordingly demanded higher rate of return. Furthermore, the correlation between the value of the debt and equity is -0.94 , which is surprisingly comparable with the -1 predicted by the Modigliani-Miller theorem. Yet, a U shape cost of capital seems to organize the data better.

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), there has been substantial effort in testing the Modigliani-Miller theorem, the evidence is however mixed. The 1958 paper Modigliani and Miller (1958) itself had a section devoted to the testing of the theorem on oil and electricity utility industry and found little association between leverage and the 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) used British data on three industry groups, chemicals, food, and metal manufacturing, and found 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 found that firm’s value increases with leverage. Robichek et al. (1967) found results consistent with a gain from leverage. Masulis (1980), Pinegar and Lease (1986), and Lee (1987) also found similar results. After thirty years of debate and testing, Miller (1988) conceded that: “Our hopes of settling the empirical issues . . .,however, have largely been disappointed.”

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 more fundamental changes. Myers (2001) therefore rightly admitted, “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. Comparing to field works, laboratory studies offer more control. Capital structure of a firm can be easily measured, and changes of the firm’ other aspects can be minimized while the capital structure of firms are adjusted. We develop our experiment on the theoretical model of Stiglitz (1969). Applying 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 their initial wealth positions. We constructed a testing environment as close as possible to the theoretical model. We want to see whether, nonetheless, experimental subjects value firms differently.

The remainder of the paper is organized as follows. In Section 2, we motivate the choice of our experimental model, and demonstrated Stiglitz (1969) and its benchmark solution. We present the experimental protocol in Section 3. Results are reported in Section 4. Finally Section 5 concludes.

2 Theory and Methodology

There were mainly two theories in the history of the cost of capital. Before 1958, the average cost of capital was usually thought to possess a U shape. The argument runs as follows: debt is initially not or at least much less risky than equity¹, 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 of debt becomes large and after some point debt becomes more expensive than equity. This results in a U shape average cost of capital.

In contrast, Modigliani and Miller's **Proposition I** (1958) stated that:

The market value of any firm is independent of its capital structure and is given by capitalizing its expected return at the rate ρ_k appropriate to its class.

Or put it differently, the average cost of capital to any firm is completely independent of its capital structure and is equal to the capitalization rate of a pure equity financed firm of its risk class. Here a risk class is a group of firms among which returns of different firms are proportional to each other. They showed that "as long as the above relation does not hold between any pair of firms in the same risk class, arbitrage will take place and restore the stated equalities".

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

2.1 The Choice of Experimental Model and Arbitrage

In examining the Modigliani-Miller theorem, a natural approach is to take the original model of Modigliani and Miller (1958) 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 structures separately in different markets, with one firm in one market. No arbitrage among these firms is possible.

Arbitrage process plays an important role in the Modigliani-Miller theorem; 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. Additionally, allowing for arbitrage among firms may exclude one potentially interesting phenomena: Suppose the majority of investors have preferences for firms with a certain capital structure. When arbitrage is possible this “anomaly” won’t be observed on the market level since it would be eliminated away by a few arbitragers, and it would have been interesting to observe this anomaly and understand why it occurs. After all, as demonstrated by Shleifer and Vishny (1997), arbitrages are seldom complete in real financial markets. Thus, by excluding arbitrage among firms we are able to address a question fundamental to the valuation of firms: *Do subjects systematically evaluate firms with different capital structure differently?*

There is one additional strength in proceeding this way. Some empirical studies show that firms with different capital structures are valued similarly. This, however, does not necessarily imply the irrelevance of capital structure to the valuation of firms. It could be that, even though 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 does cause one potential serious problem: the law of one price can not be applied straightforward anymore. The law of one price states that the same goods must sell at the same price in the same market. Without arbitrage our approach effectively cuts the link among firms, and makes the markets for the evaluation of different firms independent from each other. It is then difficult to guarantee that the market conditions, including market rules and preferences of market participants, are the same for firms with different capital structures. This could seriously blur the message of experimental results if it not properly controlled. 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. What's the worse, there still could be difference even when different markets have the same group of market participants. This is because evaluation of different firms might involve different parts of individuals' utility functions, and utility functions in general do not have the same level of risk aversion under different wealth levels.

More precisely, in economies where arbitrage is not allowed between each other differences in the evaluation of firms with different capital structures could be mainly due to two reasons:

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 students usually have similar financial backgrounds. Without proper control, this problem of sample selection could significantly limit the validity of experimental 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 is our main focus, a proper model should minimize the second possibility. For this purpose, we adapted the model of Stiglitz (1969). Stiglitz (1969) put forward a general equilibrium model, and it can be shown that the Modigliani-Miller theorem holds regardless risk attitudes and initial wealth positions of market participants.

2.2 Theoretical Model and its Benchmark Solution

Considering the following simple economy. There is one firm which exists for two periods: now (denoted by t_0) and future (denoted by t_1). The market value of the firm's equity and debt are respectively denoted by S and B , and the market value of the firm is therefore $V \equiv B + S$. The uncertain income stream \tilde{X} generated by the firm at date t_1 is a function of the state $\theta \in \Theta$, and we let $\tilde{X}(\theta)$ denote the firm's income in state θ . In this simple economy there are n investors, and the set of investors is denoted by N . Each investor i is endowed with some initial wealth of ω_i , which is composed of a fraction α_i of the firm's

total equity S and B_i unit of bonds. Since the economy is closed, we have

$$\sum_{i \in N} \alpha_i = 1 \text{ and } \sum_{i \in N} B_i = B. \quad (1)$$

By convention, one unit of bond costs one unit of money, which implies

$$\omega_i = \alpha_i S + B_i. \quad (2)$$

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 there is no bankruptcy possibility. 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.

We shall first prove the following proposition:

Proposition 1 *If there exists a general equilibrium with the firm fully financed by equity 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.*

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 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:

$$\begin{aligned} Y_i^1(\theta) &= \alpha_i \tilde{X}(\theta) + r B_i^1 \\ &= \alpha_i \tilde{X}(\theta) + r(\omega_i - \alpha_i V_1), \end{aligned} \quad (3)$$

which follows from $S_1 = V_1$ and (2).

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 $V_2 = S_2 + B^2$

and $\sum_{i \in N} B_i^2 = B^2$. Notice that the firm generates the same 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:

$$\begin{aligned} Y_i^2(\theta) &= \alpha_i(\tilde{X}(\theta) - rB^2) + rB_i^2 \\ &= \alpha_i(\tilde{X}(\theta) - rB^2) + r(\omega_i - \alpha_i S_2) \\ &= \alpha_i \tilde{X}(\theta) + r(\omega_i - \alpha_i V_2), \end{aligned} \tag{4}$$

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 $Y_i^2(\theta)$, are identical:

$$Y_i^1(\theta) = Y_i^2(\theta) \text{ for } \forall \theta \in \Theta. \tag{5}$$

Thus if a vector $(\{\alpha_i^*\}_{i \in I})$ maximizes all investors' utility in the first economy, it still does in the second economy. This proves Proposition 1.

Proposition 1 does not exclude the possibility that there could exist other equilibria where the values of firms in different economy are different. We thus proceed to show the following proposition:

Proposition 2 *The values of the firms in different economies must be the same in any equilibria.*²

We shall prove this proposition via contradiction. From Proposition 1 we know that $V_1^* = V_2^* = V^*$ can be supported as an equilibrium. Suppose there are multiple equilibria for each economy, and in the second economy there exists one equilibrium such that $V_2' > V_2^* = V^*$. That is, a higher value of the firm in the second economy can also be supported as an equilibrium. Since the value of bond doesn't change, equity must be valued higher now: $S_2' = V_2' - B^2 > V_2^* - B^2 = S_2^*$. Notice that equity's rate of return is calculated as $\frac{\tilde{X} - rB^2}{S_2}$. With \tilde{X} and B^2 remains unchanged, the increase of equity value from S_2^* to S_2' decreases the firm's rate of return on equity in the second economy. Given any risk composition of the second economy, however, the decrease of equity's rate of return should discourage the demand for equity. Since the equity market of the second economy clears at $S_2^* = V^* - B^2$, there will be over supply of equity when $S_2' > S_2^*$, a

²Stiglitz (1969) only proves Proposition 1.

contradiction to $V_2' > V^*$ being an equilibrium in the second economy. The other case $V_2' < V^*$ can be proven similarly.

Proposition 2 states that the value of the firm must be unique given the risk composition of investors, but it doesn't exclude multiple equilibria where investors might hold equity and bonds differently but still have the same value of firm. Several additional features of the model are worth noticing. Firstly, no assumptions on investors' initial wealth positions is made, which is particularly helpful when conducting laboratory experiments because it reduces the effects of sample selection on experimental 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 appealing since measuring subjects' risk attitudes are tricky and inaccurate.

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 Experimental Environments and Procedures

We had 32 subjects per session. To collect more than one independent observation per session, subjects were divided into 4 independent groups, with 8 subjects each. The group composition was kept unchanged, i.e., the 8 subjects in each group always interacted with each other through out the whole session. These 8 subjects and a firm with certain capital structure formed one closed economy. In each economy the 8 subjects were requested to evaluate the firm through a market mechanism (to be explained shortly). This closed economy was constructed as close as possible to the theoretical model. The firm was represented by a risky asset generating the following income flow:

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

For simplicity, we let

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

Bonds were perfectly safe since we didn't allow for bankruptcy. One unit of money invested in bonds yielded a gross return of 1.5, i.e., a net risk-free interest rate of 0.5. Subjects were told that they could borrow any amount of money from a bank at this interest rate.

There were 8 rounds in each session. The economies in different rounds differed only in the firms' capital structure. Firms all had 100 shares and but had different market values of bonds B that they issued. The sequence of the 8 rounds was as follows:

$$\begin{array}{lcccccccc} \text{Treatments} & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 \\ \text{Firms' } B & 50 & \Rightarrow 350 & \Rightarrow 100 & \Rightarrow 0 & \Rightarrow 400 & \Rightarrow 200 & \Rightarrow 500 & \Rightarrow 300, \end{array}$$

To discourage potential portfolio effects, only one round was randomly selected for experimental payment. Taking into account of the complexity of experimental procedure, we used the first two rounds to train subjects. The last 6 were formal rounds. Considering that some of the subjects might have learned the Modigliani-Miller theorem in the past, and that with the complete capital structure (firm's income flow and the market value of bonds) they might try to be consistent with the Modigliani-Miller theorem and thereby bias the results, we did not present subjects firms with above structure. Instead, subjects were presented the income flow of equities which were calculated as $\tilde{X} - rB$, and they were asked to price firm's shares. Let R_i^s denote the income flow of the firm in round i , that is,

$$\begin{aligned} R_1^s &= \begin{Bmatrix} \text{Gain} & \text{Prob.} \\ 11.25 & 0.5 \\ 7.25 & 0.5 \end{Bmatrix} \implies R_2^s = \begin{Bmatrix} \text{Gain} & \text{Prob.} \\ 6.75 & 0.5 \\ 2.75 & 0.5 \end{Bmatrix} \implies R_3^s = \begin{Bmatrix} \text{Gain} & \text{Prob.} \\ 10.50 & 0.5 \\ 6.50 & 0.5 \end{Bmatrix} \implies \\ R_4^s &= \begin{Bmatrix} \text{Gain} & \text{Prob.} \\ 12.00 & 0.5 \\ 8.00 & 0.5 \end{Bmatrix} \implies R_5^s = \begin{Bmatrix} \text{Gain} & \text{Prob.} \\ 6.00 & 0.5 \\ 2.00 & 0.5 \end{Bmatrix} \implies R_6^s = \begin{Bmatrix} \text{Gain} & \text{Prob.} \\ 9.00 & 0.5 \\ 5.00 & 0.5 \end{Bmatrix} \implies \\ R_7^s &= \begin{Bmatrix} \text{Gain} & \text{Prob.} \\ 4.50 & 0.5 \\ 0.50 & 0.5 \end{Bmatrix} \implies R_8^s = \begin{Bmatrix} \text{Gain} & \text{Prob.} \\ 7.50 & 0.5 \\ 3.50 & 0.5 \end{Bmatrix} \end{aligned} \quad (6)$$

More specifically, the experimental procedure in each round was as follows:

1. At the beginning of each round, subjects were given some initial endowments and were presented with a risky alternative, the income flows of one of the equities in

- (6).
2. Then market opened and a market trading mechanism became available, through which the 8 subjects in each economy could trade the risky alternative with each other. Trading quantity was restricted to integer numbers and short selling was not allowed. Notice that the highest possible value of a unit of equity was $(1200-B)/100$, and the lowest possible value of a unit of equity was $(800-B)/(100 \times 1.5)$, buying or selling prices were restricted to the range of $[(1200-B)/100, (800-B)/(100 \times 1.5)]$.
 3. After certain time, the market closed. Subjects who had a net change in share holding should either (a) pay a per-unit price equal to the market-clearing price for each unit of equity she purchased. This amount of money would be automatically deducted from her bank account. Or (b) she would receive a per-unit price equal to the market-clearing price for each unit she sold, which would be automatically deposited to the bank and would earn a net risk-free interest rate of 0.5. The feedback information of subject i would receive at this stage was:
 - the market clearing price;
 - own final holding of equity α_i and bonds B_i .

Notice that the information about the realized state were not given here, so subjects did not know how much they would have earned if this round was chosen for payment. This is to decrease potential income or wealth effects. This information was provided at the end of the experiment³. The feedback information subjects received at the end of experiment was: (1) the state of world realized for each round; (2) own net profit in each round; (3) the randomly chosen round for payment; (4) own final experimental earning. To provide subjects with stronger incentive and increase the cost of making mistakes, we granted subjects initial endowments as risk free credits and paid them only the net profits they made.

We now proceed to describe the structure of this initial endowment and explain in detail the market trading mechanism.

3.2 Initial Endowments and the Trading Mechanism

The determination of subjects' initial endowments is not straightforward. The theoretical model requires subjects to have the same endowments in different rounds. A seemingly

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

natural choice would be to endow all subjects with the same amount of money. This is unfortunately not feasible here because this amounts to know the value of the firm before the experiment.

Taking into account above considerations, we determined subjects' initial endowments in the following way: among the 8 subjects of each group, four subjects were endowed with $12\% \times 100$ shares and $12\% \times B$ units of money, and the remaining four subjects were endowed with $13\% \times 100$ shares and $13\% \times B$ units of money. Subjects' money endowments were automatically deposited to a bank. For each unit of money deposited/borrowed the bank offers/charges 1.5 at the end of the each round, 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 extremely 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' risk attitudes, and to minimize the impact of individual mistakes on market prices.

Real security markets face similar problems when determining the opening price of a stock in a new trading day. After the overnight or weekend nontrading period, uncertainty regarding a stock's fundamental value becomes higher. In order 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 operated in the following manner. When call auction became available in one round, participants were 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 would be constructed from the individual orders, and the market-clearing price maximizing trades would be chosen. While this concept is clear, its implementation was tricky and thus deserves some further remarks. In the experiment, we used the following algorithm to computer the market clearing price:

1. A buy order with price P_b and quantity Q would be transformed into a vector (P_b, P_b, \dots, P_b) with length Q . Each element of this vector can be regarded as an

unit buy order at price P_b . These vectors would then be combined to build one general buy vector, which is then sorted by buying price from high to low. Similar operation was done for sell orders, except that the resulted vector was sorted by selling price from low to high. via this procedure, a aggregate demand schedule and supply schedule were 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 were then pairwise compared (P_b^i and P_s^i). This searching process continued until a first pair i such that $P_b^i < P_s^i$ was 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

$$P_s^{i-1} \leq P \leq P_b^{i-1}.$$

Combining these two conditions, we know that the market clearing price should satisfy

$$\max\{P_s^{i-1}, P_b^i\} \leq P^* \leq \min\{P_b^{i-1}, P_s^i\}. \quad (7)$$

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

3. If there were an excess demand or supply at this market clearing price, then only the minimum quantity of the buy or sell orders would be executed.
4. Of course, it was possible that a market clearing price could not be found via this procedure if $P_b^1 < P_s^1$ or $P_b^{end} > P_s^{end}$. In this case, $P_s^1 - 0.01$ was chosen to be the market clearing price if $P_b^1 < P_s^1$, and $P_b^{end} + 0.01$ was chosen to be the market clearing price if $P_b^{end} > P_s^{end}$.

In order to further promote learning and help subjects to set “reasonable price”, the 3 minutes were divided into three trading phases, each lasted for 1 minute⁴. After each of the first two trading phases, an indicative market clearing price calculated via the above algorithm was published. The indicative market price suggests that if no one change their orders till the end of 3 minutes, all eligible orders would be executed at this price. Subjects were also told that they could always revise their orders before the end of 3 minutes. After

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

the end of 3 minutes, a final market clearing price would be calculated. Trades would then take place at this price.

4 Results

In reporting our results, we proceed as follows. First, we present an overview of trading results and firms' values across rounds. Then, we turn to our main hypothesis and investigate whether capital structure affects the value of the firm?

4.1 General Results

Due to the complexity of our experiment, a significant amounts of effort were taken to make sure that subjects understood the experimental procedure properly. We invited only subjects with relatively high analytical skills, we provided a set of control questions to check whether they really understood everything, and we provided two training rounds before the real part of experiment. Nevertheless, it is likely that subjects still could not understand the whole procedure and hence results were 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 how reliable the experimental results are. An obvious way to check the data reliability is to compare the experimental results with the market value of the firms that would be obtained by risk neutral agents. Since the risk free gross interest rate was 1.5, 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 development of the market value of the firms in the experiment. Y-axis denotes the market values of firms (equity plus bond), and x-axis denotes periods. One round consists of three consecutive periods, i.e., 1-3, 4-6, etc. Empty circles denote firms' indicative values, calculated via the indicative market clearing prices of the first two trading phases of each round. Triangles denote firms' final values, calculated by the final market clearing prices. When all points are considered, the mean median-values of the firms is 700, and it is not significantly different from 667 (two sided Wilcoxon rank sum test with p-value of 0.83). When only final market clearing prices are considered, the mean median-values of the firms changes to 677.5, and it is not statistically different from 667 (two sided Wilcoxon rank sum test with p-value of 0.79). When the first two rounds are taken out and only the final market clearing prices of the remaining 6 rounds are considered, the mean median-values of the firms 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 are reasonable.

Above results do reveal one important feature of indicative market clearing prices: The indicative market prices produced in the first two trading phases were not mature yet, and they are very volatile. This is not surprising given that these prices are not relevant for the final trades. Subjects might not submit their true orders during these two periods; they might either take this opportunity to understand the market mechanism or enter deceptive orders in the hope of fooling others. This suggests that there are two levels of learning in the experiment. The first level of learning occurs during the three trading phases of each round. This is confirmed when comparing indicative prices with final market clearing prices (respectively empty circles and triangles in figure 1). As indicated above the mean median-values of firms is closer to 667 when only final market prices are considered. 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, $p < 0.01$).

In order to examine the second level of learning: learning across rounds, the development of firms' values across rounds is examined. Before presenting the statistic model and results, however, an additional feature of the experimental design needs to be considered. In the experiment firms were valued by different groups independently, thus the market values of firms crucially depends on the composition of risk attitudes in each group. The group with subjects who are all less risk averse than subjects of another group also tends to evaluate the firm higher than that group, and this difference could be significant. Indeed, the standard deviation of the means of firms' values across group is 47.08, which is 7% of the mean median-values of the firms. Therefore, a good statistic model should take group heterogeneity into account and control it properly. For this purpose, we ran a linear regression with mixed effects⁵ based only on the final market clearing prices, where the dependent variable is firms' values, independent variables are intercept and period (t), and random effects that vary across 8 groups are the intercept. Since, as suggested above, subjects' behaviors in the first two rounds are very volatile, we ran a similar regression based only on the last 6 rounds. Formally, the model is as follows:

$$V_i = v + u_i + \alpha \cdot t + \varepsilon_i, \tag{8}$$

where $i \in \{1, 2, \dots, 8\}$ denotes the 8 independent groups, $u_i \sim N(0, \sigma_u^2)$ denotes the

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

Table 1: Regression results

Regressions	Variable	Coefficient	Std. Error	t-statistic	p-value
All rounds	v	735.9663**	25.8236	28.4997	0.0000
	t	-3.7310*	1.5191	-2.4562	0.0169
Last 6 rounds	v	681.8608**	31.9268	21.3570	0.0000
	t	-0.7503	1.7022	-0.4408	0.6615

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

random effects in the intercept for each group, and $\varepsilon_i \sim N(0, \sigma_e^2)$. Results of regression are presented in table 1.

When all rounds are considered, the coefficient for period turns out to be weakly significant (-3.7310 with $p < 0.05$), indicating that firms' values decrease over periods. However, when only the last 6 rounds are considered, this coefficient is not significant anymore, suggesting that learning mainly occurred in the first two rounds. Notice that the Modigliani-Miller theorem is an equilibrium concept, this result suggests that, due to the non-binding of indicative market clearing prices and learning, indicative market clearing prices and the final market clearing prices in the first two rounds must be excluded for analysis. From now on, we shall base our statistical analysis only on the final market clearing prices of the last 6 rounds, unless explicitly stated otherwise.

4.2 The Main Hypothesis

Now we are now ready to answer our main research question: does capital structure affect the value of the firm?

In the theory of the cost of capital, we mainly have two competing theories: 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 suggests that the cost of capital first decreases with the value of bond and then increases after the ratio of bonds exceeds a certain threshold. In the following, we shall focus on the comparison of these two theories and see which best organizes data.

Insert Figure 2 about here

Figure 2 reports the value of the firm as a function of the value of bond for each of the 8 groups. In order to give a general picture, here we use all prices. As before, empty circles denote the values of the firms based on indicative market clearing prices. Triangles denote the values of the firms based on final market clearing prices. The horizontal virtual line is $V = 667$, the value of firms implied by risk neutral rational agents, and the horizontal real line denotes the group mean of firms' values when only final market clearing prices are considered. Visually, it seems the horizontal line captures data quite well.

The Modigliani-Miller theorem suggests leverage changes the systematic risk of equities, and that $S + B = V = \text{constant}$. This implies that the market value of equity is negatively perfectly correlated with the market value of bonds

$$\text{cor}(B, S) = -1.$$

In order to see how well our experimental subjects recognized the change of systematic risk due to the change of the capital structure, we computed the correlation between the market value of equity and the market value of bonds. This correlation is negative and also equal to -1 (Spearman's $\rho = 0.94$, $p < 0.01$. First two rounds were excluded, and only the final market clearing prices were considered). Thus, it seems the change of systematic risk was 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 ran a linear regression with mixed effects. The first two rounds were excluded and only the final market clearing prices were used. Independent variable is the market value of firm. Explanatory variables includes the intercept (v), the value of bonds (B), the square of the value of bonds (B^2), and period (t). Formally the model is as follows:

$$V_i = v + u_i + \beta_1 \cdot B_i + \beta_2 \cdot B_i^2 + \beta_3 \cdot t + \varepsilon_i, \quad (9)$$

where $i \in \{1, 2, \dots, 8\}$ denotes the 8 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. We also ran regressions without B^2 , or t , or both B^2 and t . Those statistic models were however dominated by the above model in terms of AIC (Akaike's information criterion), BIC (Bayesian information criterion), and log-likelihood.

Results in Table 2 are not entirely comforting for the Modigliani-Miller theorem. The coefficient for t is significant, suggesting that learning still occurs over periods. The coefficient for B is positive and for B^2 is negative, and they are statistically significant. More importantly, the combination of these two coefficients is consistent with the U shape cost

Table 2: Regression results

Expl. Variable	Coefficient	Std. Error	t-statistic	p-value
v	670.5961**	28.1800	23.7969	0.0000
B	0.8543**	0.1732	4.9327	0.0000
B^2	-0.0014**	0.0003	-4.6043	0.0000
t	-5.7433**	1.9618	-2.9276	0.0058
Std. dev. of the random effects		$\sigma_u = 33.8011$;		
Std. dev. of the error term		$\sigma_e = 57.9559$		

** Significant at $p = 0.01$.

of capital hypothesis. Based on the theoretical model, we know that neither risk attitudes or initial wealth positions is responsible for this data pattern since the prediction of the model does not rely on either of them. To pinpoint down precisely what is responsible, however, is beyond the scope of this paper. In order to get a feeling about what's could be responsible, we looked at individual data more carefully. We found that in rounds where firms are mostly equity financed trading activity was rather limited. Notice that in this round investors do not have money endowment, and they need to borrow money from the bank in order to buy the equity. This limitation seems to discourage the buying activities significantly and accordingly pushed down the value of the equity. We may refer to this situation as “liquidity” constrained; whereas in rounds where firms had a significant proportion of bonds, equities were very risky, this seemed to also hinder the buying behaviors. We may refer to this situation as “risk” constrained. The combination of these two factors seems to be responsible for the U shape cost of capital. To find out what exactly is responsible for this data pattern, however, further research must be done.

5 Conclusion

When a firm's leverage increases, the systematic risk of 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. Applying a general equilibrium approach, we show that the Modigliani-Miller theorem holds regardless of subjects' risk attitudes or initial wealth positions. Our experimental result suggests that subjects did recognize the increased systematic risk of equity when leverage increased, and they asked for higher rate of return

for bearing this risk. Furthermore, the correlation between the value of the debt and equity is -0.94 , which is surprisingly consistent with the correlation of -1 predicted by the Modigliani-Miller theorem. Yet, this adjustment was not perfect: they underestimated the systematic risk of low leveraged equity and overestimated the systematic risk of high leveraged equity. A U shape cost of capital seems to organize the data better.

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. 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 Modigliani-Miller theorem is the only possibility.

6 The experimental instruction (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 due to random events. The show up fee of 2.5€ 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 and paid to you individually in cash. The conversion rate is

$$1ECU = 0.1\text{€}$$

Instructions are identical for all participants.

Please note that, it is possible to make a loss in this experiment. If this happens, you would have to come to our institute and do some office work. By this, you will be paid at 7€/hour. However, this can only be used to cover losses but not to increase your earnings.

Detailed information of the experiment

In this experiment, 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 through out the whole experiment. The identities of 7 other participants you play with will not be revealed to you at any time.

This experiment 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 where you earns 1.5 times the amount deposited for sure. Possession of each unit of risky alternative R allows you to obtain:

- with 50% chance the low amount of L ECU;

- with 50% chance the high amount of H ECU.

The value of L and H will be told you at the beginning of each round, and they will be different in different rounds.

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

The trading in each round lasts for 3 minutes. Specifically, the trading operates in the following way:

1. You can state whether you want to buy or sell risky alternative R , how many, and at what price per unit. This request take the following form:

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

You will not see requests made by 7 other participants.

2. After 1 minute, all requests for your group will be aggregated by a computer, and a **suggestive price** P will be published to each member of your group. This price is chosen to maximize the units of risky alternative R exchanged. The suggestive price P is not the actual trading price, rather it only indicates that, if current requests are not changed until the end of 3 minutes, then requests satisfying the following three conditions will be executed at this suggestive price P :

Trading Condition 1: all **buy** requests with prices higher than the suggestive price P , and

Trading Condition 2: all **sell** requests with selling price lower than the suggestive price P .

Trading Condition 3: for **sell** or **buy** requests at the suggestive price, only the minimum of the two will be traded. I.e, 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.

e.g, Suppose that the suggestive price is $P = 9$, and suppose that your requests were 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). Whereas if your requests were to buy 5 units of risky alternative R at the price of 8 ECU per unit, these requests will not be executed since $8 < 9$. Similarly, by

(Trading Condition 2), all sell requests with price lower or equal to $P = 9$ will be executed at $P = 9$. If your requests were to buy 10 units of R at 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 next 1 minute.
4. At the end of the second minute, again all requests will be aggregated to give a new suggestive price, and you can adjust your requests in 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 procedure 2 are executed.

The money 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:

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

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 money will be your net profit in this round. If the remaining money is negative, you will have to pay out of your own pocket.

I.e, Suppose initially we grant you M_{ini} ECU and N_{ini} units of risky alternative R , and suppose that after the trading you have M_{end} amount of money in the bank and N_{end} number of shares. If the price of risky alternative R per unit during 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:

$$M_{ini} + N_{ini} \cdot P^*$$

- The value of your final bundle (M_{end} ECU and N_{end} units of risky alternative R):

$$1.5 M_{end} + N_{end} \cdot P^* + N_{end} \times H$$

Your round earnings is calculated as follows:

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

The feedback information you receive

Feedback information at the end of each round:

- the actual trading price P^* ,
- own initial holding of money (M_{ini}) and units of risky alternative R (N_{ini}),
- the outcome risky alternative R obtains in each round,
- own final holding of money M_{end} and units of risky alternative R (N_{end}).
- own net profit in each round,

Feedback information at the end of the experiment:

- the chosen round for payment,
- own final experimental earning.

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

Your experimental earnings

At the end of the experiment, only *one* round will be randomly chosen for payment. The resulting amount will then be converted at the exchange rate of 1 ECU = €0.1 and will be immediately paid to you 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.

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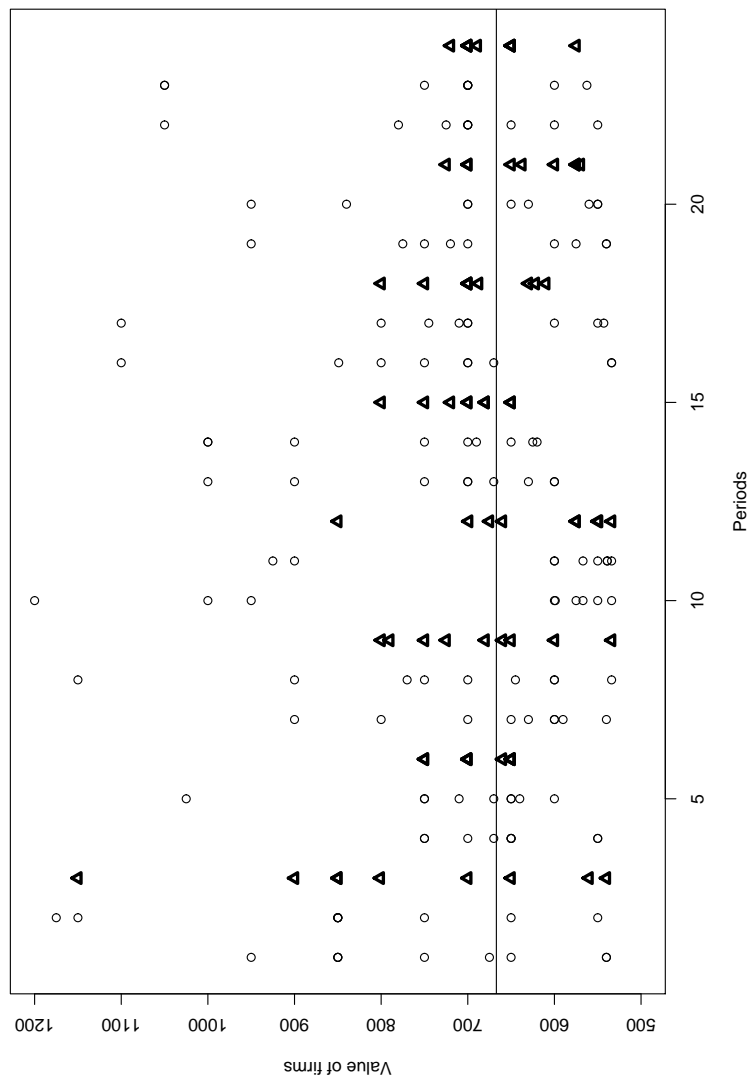


Figure 1: Firms' market values across periods

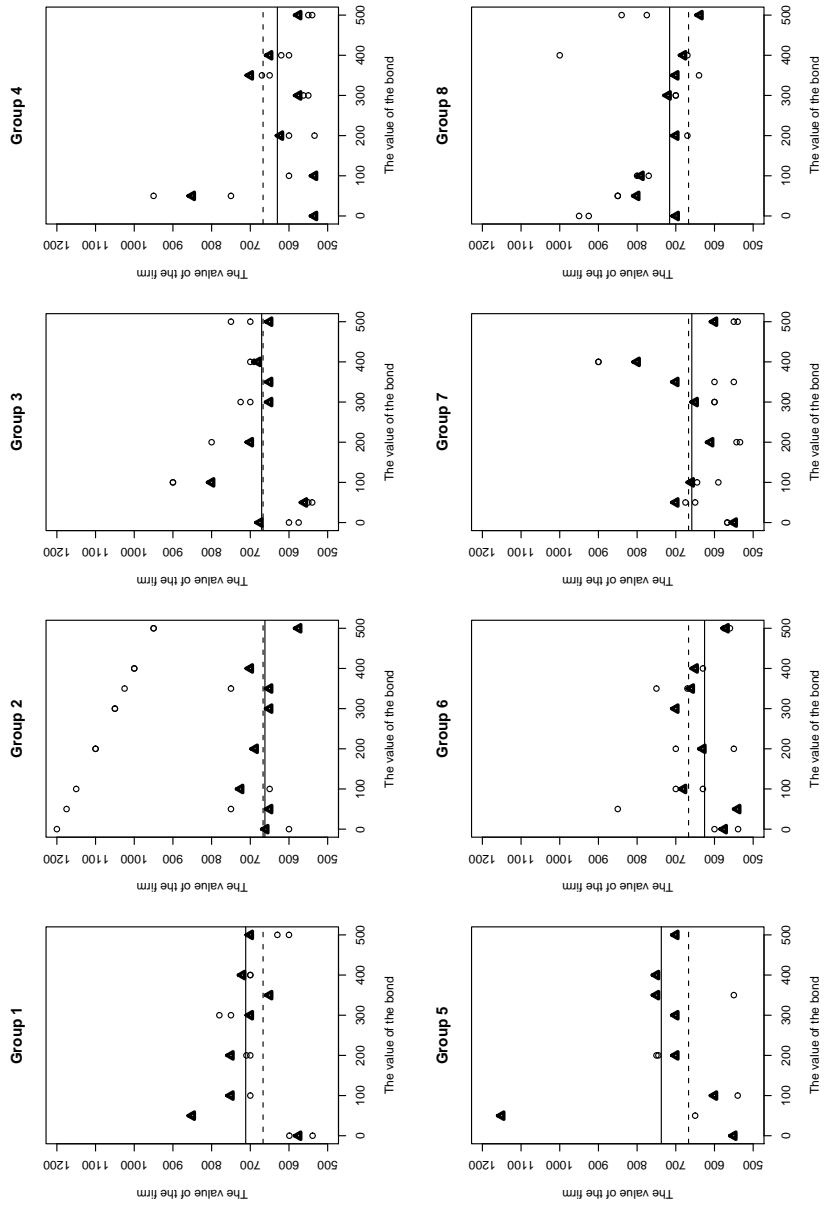


Figure 2: Firms' market values conditional on the value of the bonds for the 8 groups

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

Abstract

In this paper, we directly test the Modigliani-Miller theorem in the lab. Applying a general equilibrium approach and not allowing for arbitrage among firms with different capital structures, we are able to address this issue without making any assumptions about individuals' risk attitudes and initial wealth positions. We find that, consistent with the Modigliani-Miller theorem, experimental subjects well recognized the increased systematic risk of equity with increasing leverage and accordingly demanded higher rate of return. Furthermore, the correlation between the value of the debt and equity is -0.94 , which is surprisingly comparable with the -1 predicted by the Modigliani-Miller theorem. Yet, a U shape cost of capital seems to organize the data better.

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