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Working Paper

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Bonn Econ Discussion Papers, No. 36/2001

Provided in Cooperation with:
Bonn Graduate School of Economics (BGSE), University of Bonn

Bonn Econ Discussion Papers

Discussion Paper 36/2001

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December 2001

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The Limited Liability Effect in Experimental Duopoly Markets*

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December 10, 2001

Abstract

Brander and Lewis argue in a seminal paper (*AER*, 1986) that a firm's debt-equity ratio should have important strategic effects on product market competition. We test their model in a duopoly experiment under both, Bertrand and Cournot competition. We find that leverage has strategic effects, but those effects are much weaker than predicted by theory. Specifically, we find for price competition a general tendency towards collusion, which has the same overall consequences – but deviates from – the subgame perfect equilibrium prediction. With quantity competition subjects choose much less debt than predicted by theory. It appears that subjects recognize the strategic effects of their own debt. However, they do not (want to) acknowledge possible strategic advantages of opponents' debt.

JEL–classification numbers: L13, G33, D43.
Key words: oligopoly, bankruptcy, debt–equity ratio.

*We are grateful to the Deutsche Forschungsgemeinschaft, grant OE-198/1/1, for financial support. We thank Sebastian Kube and Elfi Thudt for excellent research assistance.

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1 Introduction

In the last 10 to 15 years a small, but growing literature has emerged that explores the interaction between product market competition and financial structure of firms.[1] In their pioneering work, Brander and Lewis (1986) observe that debt can work as a credible signal for a more aggressive position on the product market, which gives a firm a competitive advantage in a market characterized by quantity competition. Thus, firms have an incentive to choose the debt–equity ratio in a strategic way.

The key insight is that managers acting in the interest of equityholders ignore profits in bankrupt states, in which debtholders become residuals claimants of profits.[2] Since the firm is acting in an oligopolistic market, the effect of the firm's financial policy on its own production behavior strategically influences the rival firm's production behavior as well. Foresighted owners anticipate these effects and use the financial structure so as to influence the output market equilibrium in their favor. Brander and Lewis (1986) call this the limited liability effect of debt financing. In this paper we present the first experimental study of the limited liability effect of debt financing in oligopoly.[3]

We are accustomed to see theoretical results for quantity competition being exactly reversed when price competition is assumed instead. However, as pointed out by Showalter (1995), the results of Brander and Lewis (1986) are robust to this modification with the restriction that the uncertainty in the model derives from uncertain demand conditions (rather than uncertain cost conditions). With cost uncertainty, though, firms would forego debt for strategic reasons.

Thus, theory makes some very specific predictions depending on the type of product market competition (quantity versus price) and the type of uncertainty (demand versus cost). In principle, there are four empirically testable implications of the theory. (1) A firm's financial structure affects its own product market behavior. (2) A firm's financial structure affects other firms' product market behavior. (3) Those linkages depend in a particular way on

[1] For an overview, see Maksimovic (1995).

[2] See Jensen and Meckling (1976), Myers (1977).

[3] Experiments that study structurally similar problems in different contexts include Anderhub et al. (2000), Huck et al. (2000), and Engelmann and Normann (2001).

the type of product market competition and on the type of uncertainty. And (4), firms choose the debt–equity ratio strategically. In general, the available empirical data will not allow to test all those hypothesis. For this reason, the application of experimental methods yields a useful supplement to empirical studies on the matter.

In the first empirical study of the limited liability effect, Opler and Titman (1994) investigate whether firms with high leverage are more likely to experience performance losses in industry downturns than other firms. They present evidence that leveraged firms experience disproportionately large declines in sales and equity value in periods of economic distress. Hence, the financial structure affects the firm's own product market behavior, but is it not clear whether it influences the rival firms' product market behavior.

Chevalier (1995a,b) uses an ingenious data set in which leveraged buyouts (LBO) of supermarket chains work as a natural experiment of an increase in debt. In one paper (1995a) she examines how a price index changes when an incumbent supermarket chain in the city undertakes an LBO. She finds evidence of price increases following the LBO if rival firms are also highly leveraged. However, price decreases are observed following an LBO when rival firms are not highly leveraged, or when a single large competitor with low leverage controls a large share of the local market. If one assumes that one supermarket chain has only a small influence on the price index, this study supports the hypothesis that a firm's financial structure has an effect on the rivals' product market behavior.

In a second paper (1995b) Chevalier finds that an LBO announcement increases share prices of the LBO–firm's rivals indicating that debt has a mitigating effect on product market competition. She also examines the entry behavior of supermarket chains following an LBO and finds that entry seems to increase, which again points to softer product market competition.

Phillips (1995) considers whether a firm's capital structure decision has an effect on output and product pricing decisions in four industries. The results using individual firms' sales and cost data indicate that in the majority of markets industry output is negatively associated with the average industry debt ratio.

Kovenock and Phillips (1997) show that following a recapitalization, firms in industries with high concentration are more likely to close plants and less likely to invest. Rival firms are less likely to close plants and more likely to invest when the market share of leveraged firms is higher. Taken together, the evidence of the cited studies seems to support implications (1) and (2). With respect to implication (3), most studies support the hypothesis that debt softens product market competition which is contrary to what the Brander and Lewis (1986) model implies.

However, none of the above studies was designed to shed light on the question whether firms actually choose debt for strategic reasons. Two recent studies by Showalter (1999) and Wanzenried (2000) present indirect evidence in favor of the latter hypothesis. Recall that Showalter's (1995) model with price competition implies that debt has positive strategic effects only when there is demand uncertainty. While it not straightforward how to empirically distinguish between demand and cost uncertainty in a market, Showalter (1999) shows that manufacturing firms increase debt as demand uncertainty grows, but reduce debt as costs become more uncertain. Wanzenried (2000) shows that higher demand uncertainty goes along with higher leverage.

In this paper, we complement the empirical studies by analyzing strategic behavior in an experimental laboratory. We consider three different scenarios (quantity competition, price competition with cost uncertainty, and price competition with demand uncertainty) and investigate the effects limited liability has on firm's own behavior, on rival firm's behavior, and whether firms choose debt strategically.

Our experimental evidence can be summarized as follows. With quantity competition, debt has a strategic effect only on the own output. It seems that subjects do not (want to) recognize possible strategic advantages of opponents due to debt. In turn, this implies that subjects choose much less debt than predicted by Brander and Lewis (1986). With price competition, subjects in the majority choose high debt with demand uncertainty and low debt with cost uncertainty as predicted by Showalter (1995). However, since behavior in off–equilibrium subgames is not in line with theory, we explain this finding by a general tendency towards collusion rather by subgame perfect play. Possibly, the theory is supported for the wrong reason.

In the next section we introduce the experimental design with our six treatments. In Section 3 we derive the theoretical solutions and several predictions, which can then be tested experimentally. The results of those tests are presented in Section 4, followed by a Conclusion in Section 5. The Appendix contains the translation of the instructions for one of our treatments.

2 Experimental design

We study several repeated duopolies in a computerized[4] experiment. Common to all markets is that debt financing is required to produce and sell a good in a market. Due to uncertainty in the market conditions, firms will sometimes be unable to repay their debt in full, giving rise to a limited liability problem. We study both, Cournot and Bertrand competition, which are described in detail in the next two subsections. In line with the theory, for Bertrand competition we distinguish between demand and cost uncertainty.

The timing is as follows. The experiment consists of 5 "years", $y = 1, ..., 5$. Each year consists of 12 "months", $m = 1, ..., 12$. At the beginning of each year subjects are randomly matched with one other subject for the duration of this year.[5] They are informed about their total profit in each of the previous years and of the debt level of their opponent for the current year. In each month a firm chooses its action (price p_i or quantity q_i, respectively) which holds for each of its 10 independent submarkets or "countries". Since profits are stochastic, the 10 submarkets are introduced as a device to better approximate expected profits by average profits in each month.

Financing is required for each of the 10 submarkets. The debt contract of each firm is fixed for a given year and all submarkets and is characterized by a pair (b_i, d_i), where $b_i \in \{b, B\}$ denotes the amount borrowed by firm i for each of its projects, and $d_i \in \{d, D\}$ denotes the debt obligation firm i promises to pay to the creditors for this project at the end of the month out of operating profits π_i. If a firm is unable to meet its debt obligation for a given submarket, creditors are paid whatever operating profits are available. That is, a creditor for a given project receives $\min\{d_i, \pi_i\}$.

In years 1 through 4 debt contracts are fixed exogenously by the experimenters. In year 5 subjects are allowed to choose between two contracts

[4] We used the software toolbox "RatImage" developed by Abbink and Sadrieh (1995).

[5] The matching was randomly determined ahead of time in matching groups of 6 subjects with the restriction that no subjects played with another subject twice.

Table 1: **Treatments**

action	type of uncertainty	ordering	
		up	down
price	cost	C–up (2)	C–down (2)
price	demand	D–up (2)	D–down (2)
quantity		Q–up (4)	Q–down (4)

Note: The number of independent groups (each consisting of 6 subjects) is denoted in parenthesis.

(b, d) and (B, D). One treatment variable in our experiment is the ordering of exogenously chosen debt levels. In treatments "up" both firms start with low debt levels in the first year. In the second year one firm has a high debt level and the other firm a low debt level (Dd). In the third year debt levels are reversed (dD), and in the fourth year both firms have high debt levels (DD). In treatments "down" this order is exactly reversed.

up	$dd \rightarrow Dd \rightarrow dD \rightarrow DD$
down	$DD \rightarrow dD \rightarrow Dd \rightarrow dd$

This 3×2 design is summarized in Table 1.

The profit from each project is uncertain, where the uncertainty can derive either from uncertain demand conditions or uncertain cost conditions (for the linear Cournot model there is no difference between the two). The uncertainty is resolved independently for each submarket at the end of each month after actions have been chosen. Low debt levels, d, are such that firms can always meet their debt obligations. Hence, there is no default risk and, abstracting from discounting, debt value equals debt obligation, $b = d$. With high debt levels, D, firms can meet their debt obligations if and only if the state of nature is favorable, i.e. high demand or low cost, respectively. Due to limited liability, creditors will demand that $D > B$. To be plausible we chose the parameters such that a zero–(expected) profit condition holds for creditors as explained in Section 3. Table 2 lists the parameters used in the experiment.

The 96 subjects for this experiment were recruited via posters at the University of Bonn. Only about half of the subjects were economics students. In each session 12 subjects participated. Subjects were randomly

Table 2: **Parameters**

action	type of uncertainty	B	D	$d = b$
price	cost	43	62	1
price	demand	50	62	1
quantity		284	400	40

allocated to computer terminals in the lab such that they could not infer with whom they would interact. For each of our four Bertrand treatments we had 2 matching groups of 6 subjects each. To have the same number of observations for quantity competition, we used 4 matching groups for each of our two Cournot treatments.

Subjects were paid according to their total profits. Profits were denominated in "Taler". The exchange rates for German Marks in the Bertrand treatments was $2000T = 1DM$ and $10000T = 1DM$ in the Cournot treatments. The average payoff was DM 23.08 across all treatments.

Sessions lasted about 60 minutes including instruction time. Instructions (see Appendix) were written on paper and distributed in the beginning of each session. After the instructions were read, we asked subjects to answer two test questions. Once all subjects answered the test questions correctly, we started the first round.

2.1 Price competition

The cost function for each project is $C(q_i) = c_i q_i$. Demand for each project depends negatively on firm i's price and positively on its competitor's price p_j and is given by the following linear demand function for differentiated goods

$$q_i = \max\{a - 1.2p_i + p_j, 0\}. \quad (1)$$

Thus, operating profits for each project are

$$\pi_i = (p_i - c_i)q_i. \quad (2)$$

For price competition we differentiate between demand and cost uncertainty. With demand uncertainty the random variable a can assume the values 5 or

Table 3: **operating profits, Bertrand model, cost uncertainty**

your price	the other's price: 7			8			9			10		
7	101	*58.5*	16	111	*61.5*	12	123	*65*	7	132	*67.5*	3
8	99	*64*	29	110	*68.5*	27	125	*74.5*	24	135	*78.5*	22
9	90	*65.5*	41	103	*72*	41	121	*81*	41	134	*88*	42
10	79	*62*	45	94	*70.5*	47	114	*81.5*	49	128	*89.5*	51

Note: First entry in each block: profit per submarket in low cost state, *second entry*: average profit, third entry: profit in high cost state.

Table 4: **operating profits, Bertrand model, demand uncertainty**

your price	the other's price: 9			10			11			12		
9	103	*68.5*	34	110	*76*	42	120	*85.5*	51	127	*93*	59
10	107	*67.5*	28	115	*75.5*	36	127	*87*	47	135	*95.5*	56
11	108	*61*	14	118	*71*	24	131	*84.5*	38	141	*94*	47
12	105	*53*	1	116	*64*	12	132	*79.5*	27	143	*90.5*	38

Note: First entry in each block: profit per submarket in high demand state, *second entry*: average profit, third entry: profit in low demand state.

15, each with probability 1/2 while $c_i = 2$. With cost uncertainty c_i can be either 0 or 10 with probability 1/2, while $a = 10$.

To simplify the presentation all payoff information was provided via printed tables that were handed out to subjects. Only four different prices could be chosen. The prices correspond to the (unique) equilibrium prices of the four possible subgames *dd*, *Dd*, *dD* and *DD*.[6] Tables 3 and 4 show the operating profits with cost and demand uncertainty, where the first entry in each cell corresponds to the favorable state of nature while the last entry corresponds to the unfavorable one. The second entry in italics show the expected operating profit (the second entry was *not* shown to subjects).

The payoffs in Tables 3 and 4 were derived from (2) by rounding all profits to the next integer.[7] Furthermore a constant (12 for demand uncertainty, 40 for cost uncertainty) was added to all payoffs to avoid negative payoffs which would have resulted in a limited liability effect even for low debt levels.

[6] See the next section for the calculation of those equilibria.

[7] In two cases we rounded to the "wrong" integer in order to preserve payoff differences.

Table 5: **operating profits, Cournot model**

your quan.	the other's quantity											
	9			13			16			19		
9	310	*400*	490	274	*364*	454	247	*337*	427	220	*310*	400
13	306	*436*	566	254	*384*	514	215	*345*	475	176	*306*	436
16	282	*442*	602	218	*348*	538	170	*330*	490	122	*282*	442
19	240	*430*	620	164	*354*	544	107	*297*	487	50	*240*	430

Note: First entry in each block: profit per submarket in low demand state, *second entry*: average profit, third entry: profit in high demand state.

Finally, the labels of strategies correspond roughly to the actual equilibrium strategies used to calculate the payoffs. For demand uncertainty the strategy labels are simple the equilibrium strategies of the subgames rounded to the next integer. For cost uncertainty (where this procedure would have yielded strategies 7, 8, 10, 11) we relabeled strategies, which, of course should be irrelevant for subjects decisions.

2.2 Quantity competition

The inverse demand function in the Cournot treatments is given by

$$p = \max\{a - q_i - q_j, 0\}.$$

To model uncertainty, the random variable a can take the values of 50 and 30, each with probability 1/2. With a linear cost function, one could equivalently have uncertainty about marginal cost c. Here, we normalize c to zero. Operating profits for each project are given by

$$\pi_i = pq_i.$$

Again we choose four possible actions which correspond to the equilibrium quantities in the four possible subgames. Rounding to the next integer and adding a constant of 202 to all payoffs we get the payoff matrix displayed in Table 5.

3 Theoretical predictions

Theory predicts that the choice of debt levels should determine the outcomes in the product market. We consider the subgame perfect equilibrium of our two–stage game. Once debt levels are determined, the limited liability effect implies that the managers (acting in the interest of the equityholders) of the firm maximize

$$E(\max\{\pi_i - D_i, 0\}).$$

In our case this implies in particular that firms with large debt ignore states of the world in which they go bankrupt. That is, they maximize expected net profit by choosing prices on the basis of the favorable entries in Tables 3 through 5. On the other hand, firms with low debt can always meet the debt obligations. Thus, they maximize expected profit by considering expected operating profits as shown in italics in Tables 3 through 5. For example, if player 1 has high debt and player 2 low debt, then the unique equilibrium with cost uncertainty is found by considering the low cost numbers for player 1 and by considering the average profits for player 2 in Table 3. The equilibrium is (8,9) since 8 is a best reply against 9 when considering low cost numbers and 9 is a best reply to 8 when considering average profits.[8] Continuing in this fashion we obtain

Prediction S(ubgames) The equilibrium actions (price or quantity, respectively) for the subgames defined by the debt structures of two firms in a given match are

		debt levels			
action	type of uncertainty	*dd*	*Dd*	*dD*	*DD*
price	cost	(10,10)	(8,9)	(9,8)	(7,7)
price	demand	(9,9)	(11,10)	(10,11)	(12,12)
quantity		(13,13)	(19,9)	(9,19)	(16,16)

All subgames can be solved by iterative elimination of strictly dominated strategies. Thus, the equilibrium in each subgame is unique. Those equilibrium predictions are relevant for the years 1 through 4. In year five, however, the debt levels can be chosen by subjects. Using the parameters $d = b = 1$, $D = 62$, and $B = 50$ for demand uncertainty and $B = 43$ for cost uncertainty, respectively, we can derive the symmetric, reduced form game by substituting the equilibrium payoffs of the subgames.

[8] Recall that the entries given in Tables 3 through 5 are for the row player only.

cost uncertainty

	d	D
d	89.5	72
D	74.5	62.5

demand uncertainty

	d	D
d	68.5	87
D	78	90.5

Note that d is a dominant strategy with cost uncertainty, whereas D is the dominant strategy for demand uncertainty. Thus, as in Showalter's (1995) model, with cost uncertainty firms would opt for as little debt as possible, while with demand uncertainty they would choose large debt levels.

Prediction P (Showalter) With price competition and cost uncertainty players will choose minimal debt (d, d). With demand uncertainty players will choose maximal debt levels (D, D).

Finally, we can also explain how we chose the parameters b, d, B and D from Table 2. Assuming perfect competition on the capital market, a zero (expected) profit condition for creditors must hold. When a firm chooses d, it can always repay its debt. Hence, there is no need for a risk premium, and $d = b = 1$. With price competition and cost uncertainty firms choose d in equilibrium. However, if a firm were to ask for a loan D, creditors would anticipate that the competitor would choose d since d is a dominant strategy. With cost uncertainty the constellation (Dd) results in equilibrium (8,9) for which the expected return payment to the creditor is just $\frac{1}{2}62 + \frac{1}{2}24 = 43$. With demand uncertainty firms choose D in equilibrium. Hence, B results from an expected return payment of $\frac{1}{2}62 + \frac{1}{2}38 = 50$.

The same procedure yields a reduced form game for quantity competition that yields a Prisoner's dilemma structure with D as a dominant strategy as in the Brander and Lewis (1986) model.

quantity comp.

	d	D
d	384	310
D	394	329

Prediction Q (Brander–Lewis) With quantity competition players will choose maximal debt levels (D, D).

Table 6: **number of d choices**

action	type of uncertainty	matching groups up #1	up #2	down #1	down #2
price	cost	5	4	6	5
price	demand	2	3	3	2
quantity		1	4	4	5
quantity		5	4	4	4

Again, the low debt obligation $d = 40$ is chosen such that repayment is possible under all circumstances. When D is chosen under quantity competition, the opponent will also choose D (since it is a dominant strategy), and creditors can expect a repayment of $B = \frac{1}{2}400 + \frac{1}{2}170 = 285$.[9]

4 Results

Of primary interest is, of course, whether our data confirm Predictions S, P and Q of the previous section. We will begin with Predictions P and Q which state that subjects will opt for low debt levels when there is price competition and cost uncertainty and for high debt levels when there is demand uncertainty. When there is quantity competition, subjects should choose high debt levels. Table 6 presents the number of subjects who chose low debt levels d in year 5 for each of our matching groups (consisting of 6 subjects each).

For price competition and cost uncertainty most subjects follow the subgame perfect equilibrium prediction and choose low debt d. For demand uncertainty the results are less clear cut but still the majority chooses large debt as predicted. Considering each matching group as one independent observation, the difference between cost and demand uncertainty is significant at the 1% level of a one–sided MWU test.[10] Thus, our data seems to confirm Predictions P in that there is a clear difference between cost and demand uncertainty in terms of the choice of the debt level as predicted by theory.

For quantity competition, however, the results strongly deviate from the

[9] We granted creditors an expected profit of 1 to have an even amount of $D = 400$.

[10] Here we pool the data from the up and down treatments since at least for this question there seems to be no difference between those treatments.

subgame perfect equilibrium prediction D. Only one of our 8 matching groups comes close to confirming Prediction Q. Also, treating each group as one observation, the incidence of d–choices in the Q treatments is significantly higher than in the D treatments (two–sided MWU test, 5% level). Thus, one may be tempted to conclude that the limited liability effect works only for price competition. However, the following detailed analysis of behavior in the subgames will reveal that it is more complicated than that.

4.1 Price competition

When we analyze the behavior in the four possible subgames (defined by the debt levels of the two firms), it seems at first that subjects are justified in choosing the equilibrium debt levels, as the behavior in the subgames of year 5 also largely conforms to the equilibrium predictions – at least *on the equilibrium path.* With cost uncertainty the equilibrium price 10 was chosen in 94.7% of cases when both subjects in a match had low debt levels, (dd). With demand uncertainty the equilibrium price 12 was chosen in 82.3% of cases following (DD). Yet *off the equilibrium path* behavior is much less in line with the equilibrium predictions. In no off equilibrium subgame the equilibrium price is chosen by more than half of subjects. This sheds some doubt on the success of the subgame perfect equilibrium prediction which will be substantiated by the following analysis of Prediction S for years 1 through 4.

Table 7 lists the relative frequency of equilibrium play for years 1 through 4 given that a particular price is the equilibrium price in a given subgame. For example, in treatment N–up the lowest price (7 with cost uncertainty, 9 with demand uncertainty) is played in only 10.40% of the cases in which it is the equilibrium price.

Table 7 shows clearly that the equilibrium price is a good predictor only when it is the highest price (10 with cost uncertainty, 12 with demand uncertainty). In all other cases a large majority chooses non–equilibrium prices. In fact, the highest price is chosen in more than 50% of cases even when it is *not* the equilibrium price (not shown in table). Furthermore, as the average over all treatments shows there is a monotonic trend in that subjects seem to be more reluctant to choose low equilibrium prices. Thus, we can safely reject Prediction S for price competition. Subjects do not

Table 7: **frequency of equilibrium play in subgames in %**

	prices			
treatment	lowest	2nd lowest	2nd highest	highest
C–up	29.86	30.78	27.77	63.19
C–down	7.64	15.95	29.83	99.31*
N–up	10.40	15.78	19.19	70.14*
N–down	4.86	19.44	24.28	46.53
average	**13.9**	**20.49**	**25.27**	**69.79**

* highest price is equilibrium action in year 4.

choose equilibrium prices in the subgames, rather they seem to collude by choosing the highest prices.

Table 7 also shows that order effects play a role. In treatments N–up and C–down the highest price is the equilibrium price in the fourth year, whereas in the remaining treatments the highest price is the equilibrium price in the first year. In the first two treatments the percentages in which the highest price is chosen in equilibrium are clearly higher indicating that subjects may learn to cooperate with time.

Further evidence against Prediction S can be gained from considering decisions in the first years of each treatments. Since one can consider each matched pair of subjects as one independent observation, we have six observations for each treatment. Comparing the up and down treatments we find no significant difference between the (dd) and the (DD) treatments, neither for average prices in year 1, nor for median prices, nor for prices in the twelfth month of year 1. This finding holds for both, cost and demand uncertainty.

However, even if Prediction S fails in the strict sense, we can formulate weaker predictions about the effect of debt on prices.

Prediction S1' With cost uncertainty, a firm with high debt chooses lower prices than a firm with low debt. The reverse holds for demand uncertainty.

Prediction S2' With cost uncertainty, high debt implies lower prices of the opponent. Again, the reverse holds for demand uncertainty.

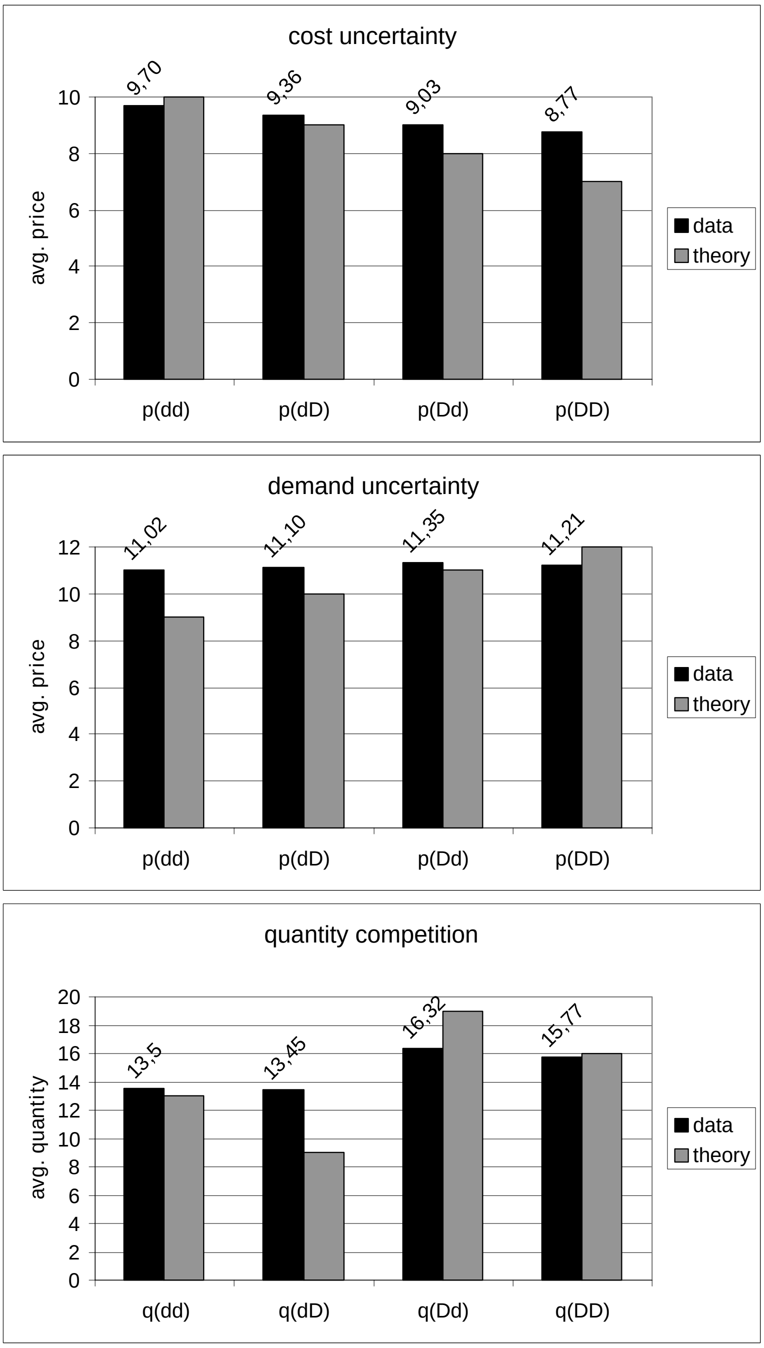

Figure 1: Average action in years 1-4 of firm 1

The first two panels of Figure 1 compare average prices with the theoretical predictions. Black bars show average prices of firm 1, $p(d_1, d_2)$, calculated for years 1 through 4 when firm 1 has debt level d_1 and firm 2 has debt level d_2, $d_i \in \{d, D\}$. Likewise, grey bars show the corresponding prices predicted by theory. Comparing $p(dd)$ with $p(Dd)$ and $p(dD)$ with $p(DD)$ reveals that for cost uncertainty an increase of firm i's debt decreases firm i's average price. For demand uncertainty, an increase of firm i's debt increases firm i's average price slightly. Comparing the behavior of each subject in those situations, we find that Prediction S1' is satisfied in 72.9% of the cases for cost uncertainty and in 45.8% of the cases for demand uncertainty.

We can also analyze the effect of firms' debt on the opponents' prices by comparing $p(dd)$ with $p(dD)$ and $p(Dd)$ with $p(DD)$. Figure 1 shows that for demand uncertainty debt has no discernible effect on opponents' prices. For cost uncertainty, average prices seem to be slightly lower when the opponent's debt is high (though this difference is not significant). Analyzing the price setting behavior for each subject in those situations reveals that Prediction S2' is confirmed in 56.25% of the cases for cost uncertainty and in 31.25% of the cases for demand uncertainty.

We see that the tendency stated in Prediction S1' is confirmed. However, this effect is much less pronounced than predicted by the equilibrium in the subgames. In fact, treating averages from each matching group as one independent observation,[11] there are no significant differences between average prices for demand uncertainty at all. For cost uncertainty, the only significant difference is that $p(dd)$ is larger than $p(DD)$ at the 5% level of a two–sided MWU test. Thus, apart from the latter case, we cannot reject the hypothesis that debt levels have no effect on prices in the subgames.

Given this reluctance of subjects to follow the equilibrium predictions in the subgames, how come that the equilibrium prediction of the entire game works fairly well (see Prediction P)? To answer this question we calculate the theoretical best replies on the first stage against the *empirically observed* behavior in the second stage. Two alternatives can be considered. First, a subject could optimize on the first stage under the assumption that behavior

[11] This yields 4 observations for p(dd) and p(DD) and 8 observations for p(dD) and p(Dd).

Table 8: **reduced form games with naive beliefs**

C–up

	d	D
d	82.17	79.89
D	76.73	70.69

C–down

	d	D
d	89.29	83.87
D	75.95	75.12

D–up

	d	D
d	80.01	81.61
D	84.09	86.35

D–down

	d	D
d	82.76	83.54
D	86.59	82.26

Table 9: **reduced form games with sophisticated beliefs**

C–up

	d	D
d	84.25	88.21
D	77.65	72.88

C–down

	d	D
d	89.37	91.12
D	79.44	78.38

D–up

	d	D
d	83.50	86.28
D	85.35	87.17

D–down

	d	D
d	88.21	88.04
D	87.35	83.75

(including his own) corresponds to the empirically observed behavior on the second stage in a particular treatment (*naive* beliefs). Second, a subject could optimize under the presumption that only the play of his potential opponents is determined by the empirically observed distribution and the subjects chooses a best reply against this on both stages (*sophisticated* beliefs).[12]

As Tables 8 and 9 show, Prediction P holds for all treatments except D–down regardless of whether we assume naive or sophisticated beliefs. Thus,

[12] The empirical distribution is calculated without excluding the subject in question. Otherwise, there would be distinct beliefs for each subject.

Table 10: **frequency of equilibrium play in subgames in %**

treatment	quantities			
	lowest	2nd lowest	2nd highest	highest
Q–up	18.08	42.70	33.35	38.90
Q–down	28.82	30.90	34.00	44.45
average	**23.45**	**36.80**	**33.68**	**41.75**

in most cases and in particular for cost uncertainty, subjects' choices of debt levels in year 5 are justified by the empirical behavior in the subgames of years 1 through 4.

To sum up, for price competition we find the following. (1) There is a general tendency towards higher, i.e. more collusive, prices (which explains the predictive power on the equilibrium path). (2) Debt levels have only minor effects on the chosen prices with the exception of cost uncertainty where (dd) yields significantly higher prices than (DD) (which explains the dismal prediction off equilibrium path). (3) Consistent with the empirical behavior in the subgames, subjects opt significantly more often for minimal debt with cost uncertainty than with demand uncertainty. Thus, while Prediction P (Showalter) is confirmed, it is confirmed for the wrong reason and not because the subgame perfect equilibrium prediction works well.

4.2 Quantity competition

The analysis of the behavior in the four possible subgames (defined by the debt levels of the two firms) shows that firms do not play according to the equilibrium solution in any subgame. Table 10 lists the relative frequency of equilibrium play for years 1 through 4 given that a particular quantity is the equilibrium quantity in a given subgame. For example, in treatment Q–up the quantity 9 is played in only 18.08% of the cases in which it is the equilibrium quantity. Table 10 shows clearly that in each case the majority chooses non–equilibrium quantities. Thus, prediction S can be rejected for quantity competition.

We can again test a weaker version of Prediction S as follows.

Prediction S1* More debt for firm i implies a higher quantity for firm i.

Prediction S2* More debt for firm i implies a lower quantity for firm j.

The lowest panel in Figure 1 shows firm i's average quantities in year 1 through 4, $q_i(d_i, d_j)$, when firm i has debt level d_i and firm j has firm level d_j. The comparison of $q(dD)$ with $q(DD)$ and $q(dd)$ with $q(Dd)$ shows that Prediction S1* is supported by the data. An increase in the own debt level yields an increase in own quantity. Counting the decisions of individual firms, we find that in 87.5% of cases a firm's quantity increases with its debt level. More formally, a MWU test rejects equality between $q(dd_i)$ and $q(Dd_i)$ for $d_i = d$ and D at a 1% level of significance in favor of $q(Dd_i) > q(dd_i)$.

The comparison of $q(dD)$ with $q(dd)$ and $q(DD)$ with $q(Dd)$ does not support Prediction S2*. An increase in the opponent's debt level does not yields a significant decrease in own quantity. Comparing a firm's behavior in two situations which differ only in the opponent's debt level, we find that Prediction S2* is confirmed in only 54.2% of the cases, which is not much different from randomness. Based on a MWU test, equality between $q(d_i d)$ and $q(d_i D)$ cannot be rejected for $d_i = d$ or D at any conventional level of significance.

The limited liability effect seems to have a significant effect when it is based on the own debt level. But subjects seem to ignore it when it is due to the indebtedness of the opponent. In other words, on the one hand subjects seem to recognize the strategic advantage of debt and try to exploit it. On the other hand, they do not want to grant their opponents an advantage and simply ignore the effects of their opponents' debt levels. This behavior, which is somewhat reminiscent of responder behavior in the ultimatum game (see e.g. Roth, 1995), has overall a beneficial effect since it avoids the Prisoner's Dilemma structure in the strategic debt game. Hence, it is not surprising that so few subjects choose D (see Table 6). When we construct the reduced form games for empirically observed behavior in the subgames we find that, in fact, minimal debt, d, becomes a dominant strategy for both, naive and sophisticated beliefs.

Q (naive beliefs)

	d	D
d	363.5	365.5
D	322.3	326.1

Q (sophisticated beliefs)

	d	D
d	377.3	378.2
D	326.5	330.8

The fact that subjects seem to ignore the debt levels of their opponents also explains why few subjects play according to the equilibrium prediction in the subgames as shown by Table 10.

5 Conclusion

In a seminal paper Brander and Lewis (1986) suggested how leverage can promote the competitiveness of a firm by making it more aggressive. The empirical tests of this hypothesis (and of its extension to price competition by Showalter, 1995) has, however, produced mixed results at best. By and large, the empirical literature supports the view that debt leads to softer competition. That is, higher debt levels yield lower quantities and higher prices.[13] However, the empirical data usually do not allow to disentangle where exactly the model's prediction breaks down. For this, one would need to know details on the type of competition (price versus quantity) and on the type of uncertainty in the market. Also, one would need to control for all other factors that may influence a firm's choice of debt.

Thus, in this paper we report on the first experimental test to study the specific linkage between financial and product market decisions, the limited liability effect of debt financing. Our main results are that with quantity competition, debt has a strategic effect only on the own output and is ignored by the opponents. In turn, this implies that subjects choose much less debt than predicted by Brander and Lewis (1986). With price competition, subjects in the majority choose high debt with demand uncertainty and low debt with cost uncertainty as predicted by Showalter (1995). However, since behavior in off–equilibrium subgames is not in line with theory, we explain this finding by a general tendency towards collusion rather than by subgame perfect play. Overall, we find that subjects behave conditionally rational as their choice of debt levels is compatible with the empirically observed behavior in the subgames.

[13] This empirical evidence is consistent with a number of alternative theoretical explanations e.g. Brander and Lewis (1988) for low debt levels; Glazer (1994); Showalter (1995) for cost uncertainty; Nier (1999); Chevalier and Scharfstein (1996), and Faure–Grimaud (2000).

A Translation of instructions[14]

Welcome to our experiment! Please take your time to read the entire instructions carefully! During the next one and a half hours you can make some money by making various decisions at a computer (the monetary units are measured in "Taler" and at the end of the experiment they will be transformed in DM at the exchange rate of 2000:1). Please do not speak with other participants during the experiment. If you have any questions regarding the procedure, please refer quietly to the experimenter.

1. Timing

For a period of 5 years you are the manager of an internationally operating company, which sells a good X in 10 different countries. There is another company, which offers the same product. In each year a different participant of this experiment will be the manager of the other company.

As manager you have to make the following decisions: A year is divided in 12 months. At the beginning of each month you choose the price of good X, which is the same in each country. The company owners have set the degree of indebtedness for the first 4 years. At the beginning of the last year you decide additionally on the extent of indebtedness of the company you manage.

2. Profits

At the beginning of each month the production of good X in every country needs to be financed through debt. Debt can be either high or low and this is fixed for the entire year. Accordingly, there is a high or low repayment obligation.

The success of your product in a country depends partly on chance. The computer decides at random and independently for each country whether business conditions are "favorable" or "unfavorable". The probabilities for both conditions are $\frac{1}{2}$.

The gross profit (profit before debt repayment) out of the sales in a country depends on the price you choose, the price of the other company, and the random business condition. Gross profit can be seen in the following table:

[14] These are the instructions for treatments C–up and C–down.

your price	the other's price							
	7		8		9		10	
7	101	16	111	12	123	7	132	3
8	99	29	110	27	125	24	135	22
9	90	41	103	41	121	41	134	42
10	79	45	94	47	114	49	128	51

In every cell of the table you find the gross profit in the unfavorable condition (in italics) and in the favorable condition. The corresponding gross profits of the other company are determined through an identical table. For example, if your price is 9 and the price of the other company is 10, your gross profit will be 42 in the unfavorable condition or 134 in the favorable condition. The gross profit of the other company is 49 or 114, respectively, which can be seen from the table above when you place yourself in the other's shoes.

Out of the gross profit from each country you have to repay your debt obligation, inasmuch as this is possible. If your debt is higher than your gross profit, you will have to pay your entire gross profit. In every case you keep the financing, which you received at the beginning.

For example, if your gross profit for a certain country is 134 Taler, your repayment obligation is 62 Taler, and the financing you received is 43 Taler, then your net profit for this country will be 115 ($= 134 - 62 + 43$) Taler. But if your gross profit were only 42 Taler, then you would be able to pay back only those 42 Taler. The net profit would be 43 ($= 42 - 42 + 43$) because you have to repay the entire gross profit but you can keep the debt financing.

At the top right of the computer screen you see your current repayment obligation as well as the repayment obligation of the other company.

At the end of a month you can see the success in the 10 countries and the price set by the other company for that month. In the next month you can set a new price. At the end of 12 months a new year will start and you are confronted with a new management in the other company.

3. Choosing the amount of the debt

In years 1-4 you cannot choose the amount of debt (and the resulting repayment obligation). The computer will tell you at the beginning of every year the amount of debt and the repayment obligation, which will be valid for the whole year. When debt is high, you will receive financing of 43 Taler and at the end of the month you have to repay 62 Taler (as far as possible). When debt is low, you will receive 1 Taler financing and you will have to repay 1 Taler.

In the 5th year you can choose between high or low debt financing.

4. Total profit

Your total profit in Taler is the sum of all the net profits from every month of the 5 years.

Thank you for your participation

Please answer the following two questions first.

Questions

1. Assume that your debt financing is high and you chose a price of 7. If the other company chooses the price 9 and the business conditions are unfavorable, what would your net profit be?

2. What would be your net profit in the above situation when business conditions were favorable?

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