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**Wirtschaftswissenschaftliche Fakultät
der Eberhard-Karls-Universität Tübingen**

**Innovation under
Financial Restrictions**

Cornelia Neff



Tübinger Diskussionsbeiträge

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Innovation under Financial Restrictions

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Abstract

How do financial constraints influence innovative activities of firms? In a two-period model of price competition with differentiated products we first analyze the incentives to innovate when both firms are self-financed. We then assume that one of the firms is financially constrained and therefore has to apply for a bank loan. If information is asymmetrically distributed between the bank and the firm, the optimal, incentive-compatible debt contract will lead to a reduction of the innovative efforts of the financially restricted firm. On the other side, the unleveraged rival will increase her innovative activities and might even become a monopolist in the second period of competition. If we finally assume that both firms are financially constrained and apply for a loan at their house bank, we can show that innovation activities are further reduced and overall welfare will decline.

JEL Classification: D 82, G 32, L 13, O 31

Key words: competition, innovation, financial contract, asymmetric information

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1 Introduction

Only recently the interactions of product market and financial decisions have come into the focus of industrial economics: One point of interest is how the capital structure of firms affects the strategic behavior in the product market (cf. the pioneering article of BRANDER and LEWIS (1986) and more recently, DASGUPTA and TITMAN (1996)). Other studies investigate how imperfections in the credit market due to asymmetric information influence the performance in the product market. The availability of outside funds, i.e. bank loans, plays a role for competition and predation between rivals and therefore influences the market structure (cf. BOLTON and SCHARFSTEIN (1990) and SNYDER (1996)). This approach stands in the tradition of the long purse story (TIROLE, 1995, 377).

In the present paper we analyze the competitive behavior of firms who engage in innovative activities. We investigate the impact of financial restrictions on the innovation activities when one of the competitors is externally financed by a bank loan. Literature on financial markets and innovation is scarce: RAMSER and STADLER (1995) analyze the impact of information asymmetries between a bank and a borrower on technological competition in a 3-step one-period framework. MAURER (1996) considers innovation under financial constraints in a two-period approach. The firm without sufficient internal resources is financed by an incentive-compatible credit contract in the design of BOLTON and SCHARFSTEIN (1990). In MAURER'S model however, the profits of the innovating firms are serially uncorrelated across periods.

In this paper we explicitly model two periods of price competition with horizontally differentiated products. Firms compete for market shares by multi-stage innovations. Empirically our model is based on the analysis of BRESHNAHAN, STERN, and TRAJTENBERG (1997), who investigate the competition for market shares through innovations in the U.S. personal computer industry in the late 1980s. Since the success of the innovation efforts is uncertain, the profit situations of the firms are stochastic. The underlying information structure in our model is such, that only the firm but not the bank knows the actual amount of profits. This means that the bank is confronted with a moral hazard problem. The bank therefore has to design an incentive-compatible loan contract. In our analysis we investigate how this financial contract affects the innovative activities of the firms as well as the product market competition and the resulting market structure.

The paper is organized as follows: We first analyze a two-period game of innovation and price competition when both firms are self-financed (section 2). We then investigate the case that one, later both of the firms depend on outside financing. We derive the optimal loan contract and analyze its impact on the innovative activities and the competitive behavior of both firms (section 3). The paper concludes with a comparison and discussion of the results.

2 A Two-Period Model of Innovation and Price Competition

In the present chapter we analyze a simple model of cost-reducing innovation and competition when both firms are able to self-finance their R&D activities.

2.1 Assumptions

The model has two time periods, period 1 and period 2. In each period the firms must pay a fixed amount F before operating in the market. In the product market, the two firms A, B compete in prices with horizontally differentiated products. The firms produce with constant marginal costs c .

Innovations lead to a stagewise reduction of marginal costs: If a firm successfully innovates in one of the (both) periods, marginal costs will decrease from a high to a middle (low) level:

$$c_h \longrightarrow c_m \longrightarrow c_l$$

Innovations are induced by firmspecific R&D activities. These R&D activities determine the probability of success θ for each innovation project.¹ On the other hand R&D activities are associated with additional costs $g(\theta)$ to the firm. We assume these costs to be increasing ($g'(\theta) > 0$) and convex ($g''(\theta) > 0$) in the success probability. For simplicity we specify the research costs as $g(\theta) = r\theta^2$.

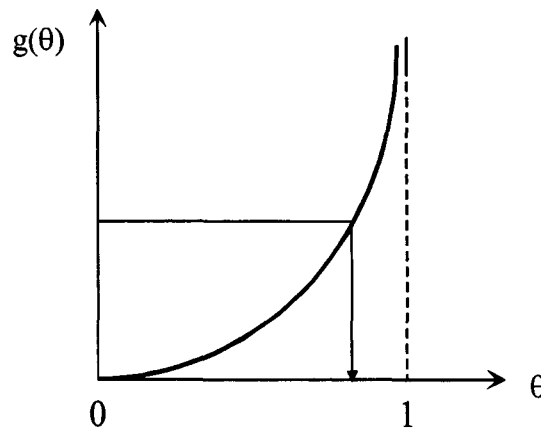


Figure 1: Research costs

Demand-side: In order to explicitly demonstrate product market dynamics, we apply the HOTELLING model of horizontal product differentiation to the two-period case. This stands in contrast to the consumer ‘switching cost’ approach of KLEMPERER (1987, 1985), in which firms only in the first period actively compete for costumers whereas in the second period market shares stay the same because high (transaction) costs prevent consumers

¹ MAURER (1996, chapter 5) interprets R&D activities as the amount of *effort* each entrepreneur spends on the realization of her innovation project.

from switching to the other product variants. The HOTELLING model grasps the fact that in dynamic technology-intensive markets, the incentives to innovate arise from period-specific, transitory market power. Firms make investments in order to gain market shares. These market shares are not fixed however but can also be lost, so firms have to defend them or even have to win them back in the following period. Therefore in the model presented here, the firms have to compete in both time periods for their customers.

Consumers have different tastes for the product variants supplied. According to their preferences they are uniformly distributed along a line of unit length $x \in [0; 1]$ (HOTELLING line). The firms are located at the edges of this line (e.g. firm A at $x = 0$ and firm B at $x = 1$). Consumers have a reservation value \bar{s} for each unit they purchase. In addition to the price, they bear a cost of T per (quadratic) unit of distance to the firm of their choice.² This cost measures the utility loss a consumer incurs when her preferred variant of product is not available in the market. Preferences are such that each consumer buys one good per period of time.

A consumer at point x buys from firm A as long as the sum of price and utility loss is smaller than at firm B :

$$p_A + T \cdot x^2 \leq p_B + T \cdot (1 - x)^2$$

The indifferent consumer therefore determines the firm-specific demand, i.e. the market share of company A :

$$(1) \quad \Leftrightarrow x_A = \frac{T + p_B - p_A}{2T}$$

We see that market share increases with the rival's price and decreases with the own price.

Supply-side: The firms are assumed to be risk-neutral profit maximizers. In each period they decide on the optimal level of R&D activities in order to reduce production costs. Whether there has been a successful innovation (= cost-reduction) or not is private information to the firm (although the rival can rationally infer it from the firm's pricing strategy). For simplicity we assume that the market offers just enough space for two differentiated products, which means that potential entrants would always make negative profits.

² We follow D'ASPREMONT, GABSZEWICZ and THISSE (1979) and use the quadratic notation for the utility-loss in order to avoid discontinuities in the profit functions.

2.2 The One-Period Case:

The game consists of two steps. First, the two symmetric firms determine simultaneously their optimal level of R&D activities. Nature then decides about success or failure of the innovation projects. In the next step, the firms set their optimal prices contingent on the realized marginal costs. After this, products are sold and profits are realized. We solve this game by backward-induction.

Pricing strategy:

The objective function of a firm consists of the profit function:

$$(2) \quad \Pi_i = (p_i - c)x_i - F - g(\theta_i) = (p_i - c)\left(\frac{T + p_j - p_i}{2T}\right) - F - g(\theta_i), \quad i, j = A, B, i \neq j.$$

Besides the term of price-cost margin times quantity sold (which we define as gross profits) it comprises the fixed costs for overall production F as well as R&D expenditures $g(\theta)$.

The optimal prices are set according to the first order condition $\partial \Pi_i / \partial p_i = 0$, $i=A, B$. We solve for the (own) price and obtain the reaction function. The NASH-equilibrium lies at the intersection of these reaction functions. Depending on the results of the innovative activities we derive the following prices and corresponding gross profits for each firm in the first period :

Situation	price	market share	gross profit
(11) both firms are successful	$p_i^{11} = T + c_m$	$x_i = 50 \%$	$\Pi_i^{11} = \frac{T}{2}$
(10) only firm i is successful	$p_i^{10} = T + \frac{1}{3}c_h + \frac{2}{3}c_m$	x_i increases	$\Pi_i^{10} = \frac{[T + \frac{1}{3}(c_h - c_m)]^2}{2T}$
(00) both firms fail	$p_i^{00} = T + c_h$	$x_i = 50 \%$	$\Pi_i^{00} = \frac{T}{2}$
(01) only firm i fails	$p_i^{01} = T + \frac{2}{3}c_h + \frac{1}{3}c_m$	x_i decreases	$\Pi_i^{01} = \frac{[T - \frac{1}{3}(c_h - c_m)]^2}{2T}$

Table 1: Prices and profits of the first period

We concentrate on firm i since prices and profits are mutually symmetric. Profits are highest when a firm successfully innovates and the rival does not. In the asymmetric cases, profits depend on the difference between high and middle levels of marginal costs ($c_h - c_m$). The following relation holds for the first-period profits :

$$\Pi_i^{10} > \Pi_i^{11} = \Pi_i^{00} > \Pi_i^{01}.$$

We see that profits are highest in case of a single innovation. Moreover, profits are equal in the symmetric cases, $\Pi^I = \Pi^0$, which is due to the assumed price competition in the HOTELLING-model. Thus, the model demonstrates that profits are not based on the absolute but on the relative (i.e. market position) performance of a firm.

R&D Activities: In order to determine the optimal level of R&D activities we have to calculate the expected value of the first-period profits. Firms are supposed to be risk-neutral.

$$(3) \quad \bar{\Pi}_i^{t=1} = \theta_i \theta_j \Pi_i^{11} + \theta_i (1 - \theta_j) \Pi_i^{10} + (1 - \theta_i) (1 - \theta_j) \Pi_i^{00} + (1 - \theta_i) \theta_j \Pi_i^{01} - g(\theta_i) - F,$$

for $i, j = A, B, i \neq j$.

The firm chooses the success probability θ_i° that maximizes the expected per-period profit less the R&D expenses $g(\theta)$ and the fixed operating costs F . The first order condition to this problem is

$$(4) \quad g'(\theta_i) = \theta_j \cdot (\Pi_i^{11} + \Pi_i^{00} - \Pi_i^{10} - \Pi_i^{01}) + \Pi_i^{10} - \Pi_i^{00}, \quad i, j = A, B, i \neq j.$$

In the optimum, marginal R&D expenditures must equal marginal profits from innovation.

The reaction functions of the R&D activities exhibit strategic substitutability³:

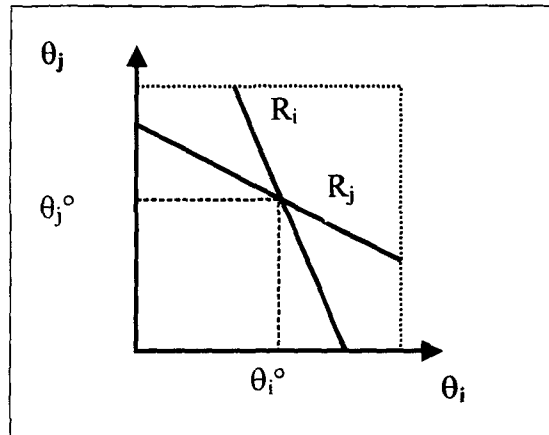


Fig. 2: R&D reaction functions

In the symmetric equilibrium $\theta_i = \theta_j = \theta^\circ$ and therefore

$$(5) \quad \theta_i^\circ = \frac{\Pi_i^{10} - \Pi_i^{00}}{2r - \Pi_i^{11} - \Pi_i^{00} + \Pi_i^{10} + \Pi_i^{01}} = \theta_j^\circ$$

with $2r = g'(\theta) / \theta$.

³ With research costs specified as $g(\theta) = r\theta^2$, we derive linear reaction functions. Using research cost functions of higher order complicates the analysis tremendously without changing the qualitative results.

The optimal level of the R&D activities mainly depends on the difference between the profits Π_i^{10} and Π_i^{00} that the firm obtains in the case of own single innovation and the case in which none of the firms innovates. The term $2r$ in the denominator of (5) is influenced by the slope of the R&D-cost function.

2.3 The Two-Period Case

We now extend the time horizon of our model to two periods of innovation and product market competition.

In $t=1$ the two symmetric firms decide upon their R&D activities. Nature then determines the success of the innovation projects. The firms choose their optimal prices contingent on their marginal costs, then products are sold, and finally profits are realized. The first period is equivalent to the one-period case.

In $t=2$ the competitive position of a firm is determined by the innovation results of the previous period. There are four possible outcomes: either both firms have innovated (11) or none of them has (00), or firm A is the only innovator (10) or firm B has innovated while firm A has failed (01).⁴ Depending on their relative market position, the firms again simultaneously choose their optimal R&D levels. Nature then determines whether the R&D efforts will be successful or not. Thereafter the firms learn their marginal costs of production and set the optimal prices accordingly. Consumers buy the products supplied and profits are realized.

Again, we solve for the subgame-perfect NASH-equilibrium of this two-stage two-period game by backward induction.

⁴ We denote the results from R&D activities by „1“ for success by „0“ for failure. The first number represents the situation for firm i , the second for firm j .

2.3.1 Period 2

The scenarii in the second period are as follows:

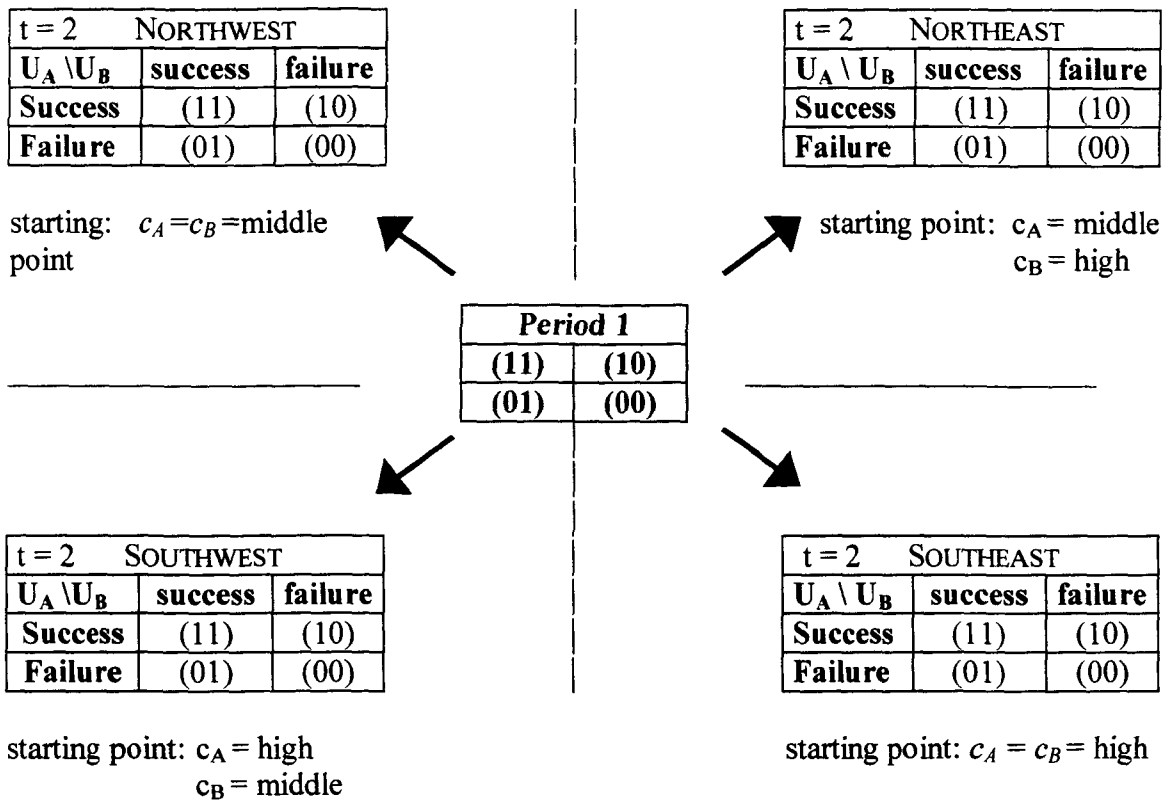


Figure 3: Market outcomes in the second period

Which of the scenarii is relevant for the second period depends on the market result of the first period. When analyzing the profit opportunities we see that the HOTELLING-model reports equal profits for equal market positions.

Defining μ as the R&D activities of the second period, μ° denotes the level of R&D activities in the symmetric cases, and μ^L , μ^F represent the R&D levels in the asymmetric case for the successful firm (who has the cost-advantage) and the unsuccessful firm respectively. Note that for a firm that has not innovated in the first period it is not possible to leapfrog from a high to a low cost level, i.e. in the case of success this firm can only reduce her marginal costs to a medium level.

We now describe the market outcomes of figure 3.

„SOUTHEAST“: In this case, none of the firms has innovated in the first period, both have had to produce with high costs. Decision-making in the second period is a mere repeating of the situation in the „isolated“ first period. Pricing strategy and profit possibilities are as shown as in *Table 1*. R&D activities are identical to equation (5): $\mu_A = \mu_B = \mu^\circ = \theta^\circ$. The expected gross profit is $\bar{\Pi}_i^{S\&E}$, from which $g(\mu^\circ)$ and F have to be deducted. This scenario occurs with probability $(1-\theta_A)(1-\theta_B)$.

In the case „NORTHWEST“, the situation is quite similar. Both firms had successfully reduced marginal costs in the first period. Since their competitive position is symmetric, incentives to further innovate are again $\mu_A = \mu_B = \mu^\circ = \theta^\circ$. Expected profits for both firms likewise amount to $\bar{\Pi}_i^{NW} - g(\mu^\circ) - F$ with the only difference that the product prices are lower. This scenario occurs with probability $\theta_A \theta_B$.

More interesting are the cases with asymmetric starting position in period 2.

In the case „SOUTHWEST“, firm B had realized a cost advantage over firm A in the first period. In the second period firm A will only regain her competitive position if she innovates and B does not. Otherwise, firm B can keep her cost advantage (if both firms innovate or none of them). Or firm B can even enhance her cost-advantage, if she succeeds in lowering costs to c_l^B while A fails to innovate for a second time. After setting the optimal prices the profit situation for firm A (the cost-follower) in the case SOUTHWEST is as follows:

t= 2 SOUTHWEST	B succeeds	B fails to innovate
A succeeds	$\Pi_A^{SW-11} = \frac{[T - \frac{1}{3}(c_m - c_l)]^2}{2T}$	$\Pi_A^{SW-10} = \frac{T}{2}$
A fails	$\Pi_A^{SW-01} = \frac{[T - \frac{1}{3}(c_h - c_l)]^2}{2T}$	$\Pi_A^{SW-00} = \frac{[T - \frac{1}{3}(c_h - c_m)]^2}{2T}$

Table 2: Second period profits of the cost-follower

We see that profits are highest in the case (10) and lowest in the case (01). The profits Π_A^{SW-11} and Π_A^{SW-00} are equal as long as the cost differences between the high, middle, and low levels are the same.

In contrast to this, the single innovator of period 1 has always better profit possibilities. We consider the profit situation for the „cost-leader“ from the viewpoint of firm A in the case NORTHEAST:

t= 2 NORTHEAST	B succeeds	B fails to innovate
A succeeds	$\Pi_A^{NE-11} = \frac{[T + \frac{1}{3}(c_m - c_l)]^2}{2T}$	$\Pi_A^{NE-10} = \frac{[T + \frac{1}{3}(c_h - c_l)]^2}{2T}$
A fails	$\Pi_A^{NE-01} = \frac{T}{2}$	$\Pi_A^{NE-00} = \frac{[T + \frac{1}{3}(c_h - c_m)]^2}{2T}$

Table 3: Second period profits of the cost-leader

We see that the profits of the cost-leader are positively influenced by the difference of the marginal costs between her and her rival. Here again profits are highest in the case (10) and lowest in the case (01).

Taking the expected profits into account we now can calculate the optimal R&D activities for the follower and the leader:

$$(6) \quad \mu^F = \frac{\Pi_F^{10} - \Pi_F^{00} + (\Pi_F^{11} + \Pi_F^{00} - \Pi_F^{10} - \Pi_F^{01})(\Pi_L^{01} - \Pi_L^{00})}{2r - (\Pi_F^{11} + \Pi_F^{00} - \Pi_F^{10} - \Pi_F^{01})(\Pi_L^{11} + \Pi_L^{00} - \Pi_L^{10} - \Pi_L^{01})}$$

$$(7) \quad \mu^L = \frac{\Pi_L^{01} - \Pi_L^{00} + (\Pi_L^{11} + \Pi_L^{00} - \Pi_L^{10} - \Pi_L^{01})(\Pi_F^{10} - \Pi_F^{00})}{2r - (\Pi_F^{11} + \Pi_F^{00} - \Pi_F^{10} - \Pi_F^{01})(\Pi_L^{11} + \Pi_L^{00} - \Pi_L^{10} - \Pi_L^{01})}$$

with $2r = g'(\mu)/\mu$.

Π_F^{10} stands for the profit the cost-follower earns in the case (10), i.e. when firm A is the only successful innovator in period 2. The amount equals to Π_A^{SW-10} . Likewise Π_L^{01} stands for the profits of the cost-leader. We see that the denominators in both formulas are the same and that the optimal level of R&D activities is influenced by the profit values of both firms. The increase in profits from the case of no innovation to the case of solo innovation is the main factor that determines the level of optimal research activities.

Proposition 1:⁵

For the optimal level of R&D activities in the second period, the following relation holds:

$$\mu^F < \mu^L < \mu^0.$$

This means that in the asymmetric case, both the cost-leader and the cost-follower will reduce their R&D activities compared to the level in the symmetric case μ^0 .

The cost-follower from period 1 can at most regain her market shares but cannot acquire new customers because in the present model leapfrogging is not possible. Therefore her incentives to engage in R&D activities are low. On the other hand, the leader already enjoys a cost-advantage from the previous period. If she further engages in R&D activities, she cannot reap all the benefits from innovation because of the consumers' preferences for the heterogeneous products. Since she cares most about holding her market position, incentives to innovate for the cost-leader μ^L are lower than in the symmetric case μ^0 .

With the optimal values for μ^L and μ^F we now can calculate the expected profits for the leader and the follower in the scenarii NORTHEAST and SOUTHWEST: $\bar{\Pi}_A^{NE}$ and $\bar{\Pi}_A^{SW}$ (and for firm B vice versa).

2.3.2 Period 1

Applying backward induction we now take into account that firms will anticipate the expected second-period profits while choosing their optimal R&D levels in the first period. For simplicity the interest rate is assumed to be zero. We determine the ,new' optimal

⁵ Proofs of all propositions are available from the author on request.

R&D activity of the first period by including the expected second-period profits into the maximization problem. We therefore get for the R&D equilibrium (fixed costs F eliminate each other):

(5')

$$\theta_A^* = \frac{\Pi_A^{10} + [\bar{\Pi}_A^{NE} - g(\mu^L)] - \Pi_A^{00} - [\bar{\Pi}_A^{SE} - g(\mu^0)]}{2r - \Pi_A^{11} - [\bar{\Pi}_A^{SE} - g(\mu^0)] - \Pi_A^{00} - [\bar{\Pi}_A^{SE} - g(\mu^0)] + \Pi_A^{10} + [\bar{\Pi}_A^{NE} - g(\mu^L)] + \Pi_A^{01} + [\bar{\Pi}_A^{SW} - g(\mu^F)]}$$

with $2r = g'(\theta) / \theta$.

Proposition 2:

The optimal R&D activities in the first period increase from θ^0 (equation 5) to θ^ (equation 5') if the second period of competition is taken into account:*

$$\theta^* > \theta^0.$$

This result stands in contrast to that in the model of MAURER (1996, 119p.), where innovation efforts are independent of each other and identical in both periods. As a consequence of the higher R&D expenditures $g(\theta^*)$ in this model, expected net first-period profits for both firms will decrease.

3 Financial constraints and competition

In this section we will analyze the innovation activities and the product market competition when the firms lack of sufficient internal funds and therefore are dependent on outside funding. Outside funding is provided by rational investors, i.e. banks. In part (3.2) we assume that only one of the firms is financially restricted. We derive the optimal financial contract between this leveraged firm and the bank. Then we compare the results for the innovative activities in the constrained and in the unconstrained equilibria. In part (3.3) we finally assume that both firms need external funding. We investigate the changes in the innovation activities and the market structure which are a result of the financial constraints.

3.1 Assumptions

We assume that firm i , $i=A,B$, does not have sufficient internal funds to cover both R&D expenditures and fixed production costs. Since the R&D expenditures have to be self-financed because of their stochastic results, only the fixed amount F can be externally financed by a bank loan. We point out again that the expected value of firm i 's investment is positive

$$(8) \quad F \leq \bar{\Pi}_i^{t-1} - g(\theta_i^*).$$

Thus, if firm i could finance herself through internal funding, she would invest in each period. To make things interesting however we assume that fixed costs F are higher than the profits in the case of a cost-follower (01) net of research expenditures costs $g(\theta^*)$

$$(9) \quad F > \Pi^{01} - g(\theta^*).$$

Therefore with positive probability firm i will incur losses.

Information structure: If firm i applies for a bank loan, an information problem arises between the firm and the bank because of the stochastic profit situation. Although the bank is perfectly informed about the competitive structure of the game, i.e. the profit possibilities in the first and second period, and the R&D cost-function of the firm, the bank is unable to observe which event (success or failure) nature assigns to the innovative efforts of the firms. It is further assumed that the bank cannot observe product prices either: Only a firm operating in the market knows the exact price constellations and is able to derive the innovation success of her competitor. As a consequence the bank does not know which profit firm i has finally realized. Because of this information advantage of firm i the bank is confronted with a problem of moral hazard with hidden knowledge: firm i has always an incentive to lie and to announce low profits in order to reduce repayments of the loan.

BOLTON and SCHARFSTEIN (1990) show how this moral hazard problem can be mitigated in a two-period financial contract: the contract simply has to specify that in the case of low reported profits the bank will reduce or even deny completely follow-up financing in the second period.

3.2. One externally financed firm

3.2.1 The optimal financial contract

Let the leveraged firm be firm A while the unleveraged rival is firm B . The bank makes a take-it-or-leave-it offer to firm A . For the moment we assume that the bank has all the bargaining power. The amount of credit in each period is F . We further suppose that the firm cannot offset borrowing needs against first-period profits.

The contract is based on reported profits. $R^{u,v}$ ($u, v = 0, 1$) are the repayments specified if first period profits are reported to be $\Pi^{u,v}$. The only threat the bank can exert on firm A to announce profits truthfully is the refusal to provide finance in the second period. By $\beta^{u,v}$ we denote the probability of firm A to receive further finance when reported profits are $\Pi^{u,v}$. (We assume that there exists an enforceable randomizing scheme if $\beta^{u,v}$ strictly lays between zero and one). With $R^{t=2}$ we characterize the repayments of the second period. Notice that these repayments have to be all equal because of the moral hazard problem, i.e. in $t=2$ there is no more need for future finance and the bank has lost any threat potential.

The optimal financing contract is a direct revelation mechanism that specifies repayments and refinance probabilities $\{R^{u,v}, \beta^{u,v}, R^{t=2}\}$. It maximizes the expected profits W of the bank subject to (i) the limited liability constraints (ii) the condition for the optimal R&D activities of the firm, and (iii) the incentive compatibility constraints which ensure that firm A reports her profits truthfully.

The maximization problem of the bank can be formulated as follows:

$$(10) \quad \max W = \theta_A \theta_B \cdot R^{11} + \theta_A (1 - \theta_B) \cdot R^{10} + (1 - \theta_A) \theta_B \cdot R^{01} + (1 - \theta_A) (1 - \theta_B) \cdot R^{00} - F + \\ \left[\beta^{11} \theta_A \theta_B + \beta^{10} \theta_A (1 - \theta_B) + \beta^{01} (1 - \theta_A) \theta_B + \beta^{00} (1 - \theta_A) (1 - \theta_B) \right] (R^{t=2} - F)$$

subject to the limited liability constraints:

$$(11) \quad \Pi^{u,v} - g(\theta_A) \geq R^{u,v} \quad (u, v = 0, 1),$$

the condition for the optimal level of R&D activities:

$$(12) \quad g'(\theta_A) = \theta_B \left[\Pi^{11} - R^{11} + \beta^{11} (\bar{\Pi}_A^{NW} - g(\mu^o) - R^{t=2}) - \Pi^{01} + R^{01} - \beta^{01} (\bar{\Pi}_A^{SW} - g(\mu^F) - R^{t=2}) \right] + \\ (1 - \theta_B) \left[\Pi^{10} - R^{10} + \beta^{10} (\bar{\Pi}_A^{NE} - g(\mu^L) - R^{t=2}) - \Pi^{00} + R^{00} - \beta^{00} (\bar{\Pi}_A^{SE} - g(\mu^o) - R^{t=2}) \right],$$

and the incentive compatibility constraints:

$$(13) \quad \Pi^{10} - R^{10} + \beta^{10} (\bar{\Pi}_A^{NE} - g(\mu_A^L) - R^{t=2}) \geq \Pi^{10} - R^{00} + \beta^{00} (\bar{\Pi}_A^{NE} - g(\mu_A^L) - R^{t=2}),$$

$$(14) \quad \Pi^{10} - R^{10} + \beta^{10} (\bar{\Pi}_A^{NE} - g(\mu_A^L) - R^{t=2}) \geq \Pi^{10} - R^{01} + \beta^{01} (\bar{\Pi}_A^{NE} - g(\mu_A^L) - R^{t=2}),$$

$$(15) \quad \Pi^{00} - R^{00} + \beta^{00} (\bar{\Pi}_A^{SE} - g(\mu^o) - R^{t=2}) \geq \Pi^{00} - R^{01} + \beta^{01} (\bar{\Pi}_A^{SE} - g(\mu^o) - R^{t=2}).$$

The objective function of the bank (10) consists of the expected repayments less the amount borrowed in the first-period plus the total probability of future finance multiplied with the net repayments of the second period.

The limited liability constraints (11) imply that repayments must not exceed the actual gross profits net of innovation costs.

Equation (12) represents the modified first order condition (4) for the optimal R&D activities of firm A , i.e. when expected profits in both periods have altered because of the required loan repayments.

The incentive compatibility constraints (13), (14) and (15) ensure that it is always advantageous for the firm to reveal the actual profits and not to report lower profits instead. Since first-period profits are identical when the firms are in equal market positions (case (11) and (00)) we have formulated these incentive constraints only for case (00). We therefore have to consider only three instead of the original six incentive compatibility

conditions. Moreover condition (14) is redundant because from comparison with (13) and (15) we see that the incentive compatibility constraint (13) is more restrictive than equation (14).

3.2.2 Solution

To solve the optimization problem we start with the assumption that the amount borrowed is higher than lowest first-period profit: $F > \Pi_A^{01} - g(\theta^*)$. The bank therefore incurs losses when firm *B* successfully innovates and firm *A* fails to do so. In this case (01) there will be no follow-up financing for firm *A*: $\beta^{01} = 0$, since firm *A* cannot credibly commit herself to cover the present losses by higher repayments in period 2. The repayment in that case equals $R^{01} = \Pi_A^{01} - g(\theta^*)$.

Because of the moral hazard problem repayments in the second period equal the amount of the smallest profit of the cases with follow-up financing. Therefore we have $R^{t=2} = \Pi_{SE}^{01} - g(\mu^o)$. This implies that in the second period the bank is always facing a negative return on investment and has to be forced to actually extend the subsequent loan.

Inserting these results into the incentive compatibility constraints and taking the limited liability conditions into account we can derive the values for the other repayments and the refinance probabilities:⁶

Case (3.2.1): In this case the refinance probabilities $\beta^{\mu,v}$ take the value of either zero or one. It is relevant when expected second-period profits of the case SOUTHEAST are smaller than the profits in the symmetric market position of period 1.⁷ In other words: if the optimal innovation probability in the symmetric scenario of period 2 is less than one half ($\mu^o < 0,5$), the refinance probabilities $\beta^{\mu,v}$ are either zero or one and the repayments R^{00} , R^{11} and R^{10} are all the same.

case (3.2.1)	$\Pi^{01} < \bar{\Pi}_{SE}^{t=2} < \Pi^{00} = \Pi^{11} < \Pi^{10}$	
Refinance probability	$\beta^{01} = 0$	$\beta^{00} = \beta^{11} = \beta^{10} = 1$
Repayments in t=1	$R^{01} = \Pi^{01} - g(\theta_A^*)$	$R^{00} = R^{11} = R^{10} = \bar{\Pi}_{SE}^{t=2} - g(\theta_A^*)$
Repayments in t=2	--	$R^{t=2} = \Pi_{SE}^{01} - g(\mu^o)$

Table 4: Optimal repayments in case (3.2.1)

Case (3.2.2): In this slightly more complicated case the refinance probabilities can take three different values: β will equal zero for the cost-follower, β will lay between zero and one in symmetric cost situations, and β will equal one for the cost-leader. This case is

⁶ We have to distinguish between the two different cases since we have not specified the exact research cost function nor the parameters for the demand side.

⁷ This condition is a result derived in the maximization process.

relevant when expected second-period profits of the case SOUTHEAST are higher than the first-period profits of the symmetric situation, i.e. when the innovation probability of the case SOUTHEAST is higher than one half ($\mu^o \geq 0,5$):

case (3.2.2)	$\Pi^{01} < \Pi^{00} = \Pi^{11} < \bar{\Pi}_{SE}^{t=2} < \Pi^{10}$		
refinance probability	$\beta^{01} = 0$	$\beta^{00} = \frac{\Pi^{00} - \Pi^{01}}{\bar{\Pi}_{SE}^{t=2} - \Pi^{01}} < 1$	$\beta^{10} = 1$
repayments in $t=1$	$R^{01} = \Pi^{01} - g(\theta_A^*)$	$R^{00} = \Pi^{00} - g(\theta_A^*)$	$R^{10} \leq (\bar{\Pi}_{NE}^{t=2} - g(\mu^L) - R^{t=2}) * (\beta^{10} - \beta^{00}) + R^{00}$
repayments in $t=2$	--	$R^{t=2} = \Pi_{SE}^{01} - g(\mu^o)$	$R^{t=2} = \Pi_{SE}^{01} - g(\mu^o)$

Table 5: Optimal repayments in case (3.2.2)

Here we see that if the refinance probability β^{10} is higher than β^{00} , repayments R^{10} of the single innovator must not exceed repayments R^{00} plus the probability difference multiplied with expected net second period profits for incentive compatibility reasons.

We finally insert these results into the condition for the level of optimal R&D activity (12). There however we have to take into account that the optimal level of R&D activity of firm B, θ_B , will also be affected by the financial contract of firm A: If the bank refuses to refinance firm A in the second period, firm A is obliged to exit the market and firm B can realize monopoly profits in $t=2$. Contingent on the level of these monopoly profits, firm B will drastically increase her first period R&D activities whereas firm A will reduce her innovative efforts. We therefore can state for the modified levels of optimal R&D activities that are altered by the financial restriction (FR) of firm A:

Proposition 3: *If firm A is financially restricted, her optimal level of first-period R&D activities decreases whereas the optimal level of R&D activities of the unleveraged rival B increases*

$$\theta_A^{FR*} < \theta^* < \theta_B^{FR*}.$$

Graphically we see that (in comparison with *Figure 2*) both R&D reaction functions will shift as a consequence of the borrowing needs of firm *A*. The slope of the reaction function of the rival R_B is influenced by the size of the monopoly profits, whereas the position of the reaction function R_A depends on the relevant refinancing situation for firm *A* (case (3.2.1) or (3.2.2)):

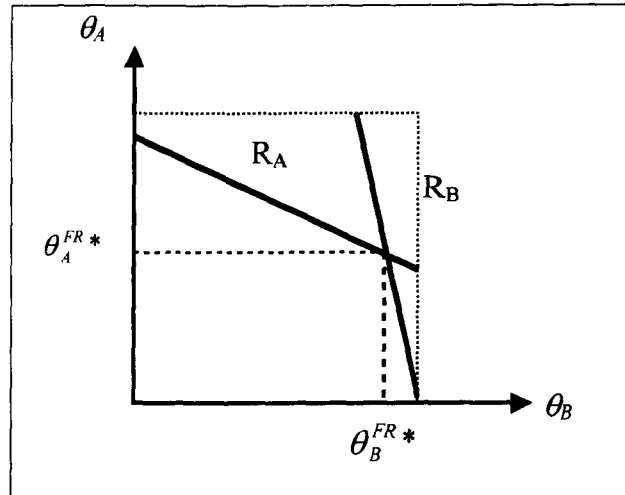


Fig. 4: R&D reaction functions under financial constraints – case (3.2.1): $\beta^{00} = \beta^{11} = 1$

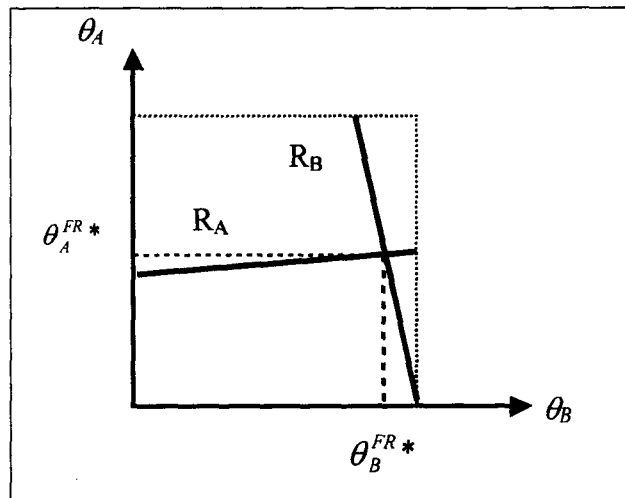


Fig. 5: R&D reaction functions under financial constraints – case (3.2.2): $\beta^{00} = \beta^{11} < 1$

Substituting the results for $\{\theta_A^{FR*}, \theta_B^{FR*}, R^{01}, R^{00}, R^{11}, R^{10}, \beta^{01}, \beta^{00}, \beta^{11}, \beta^{10}, \text{ and } R^{i=2}\}$ in equation (10) we can calculate the expected profits W for the bank. As long as the expected profits are positive, the financial contract is actually offered to firm *A*. Since the profit situation of the bank is contingent on the amount of loan extended, $W(\cdot, F)$, the bank will impose an upper bound on F .

3.2.3 Comparison between internally and externally financed innovation behavior

The innovative activities of the financially restricted firm decrease remarkably in the first period. The reason is that large parts of the firm's profits are transferred to the bank via the financial contract. However, the expected profits of this firm remain positive: though all the bargaining power is on the side of the bank, the bank is not able to reduce firm A 's profits to zero because of the limited liability constraint and the moral hazard problem.

On the other side first-period innovation efforts of the rival firm will increase drastically: The rival anticipates the chance to realize monopoly profits in the second period if she is the only innovator in the first period because in this case firm A will be denied further credit. Therefore firm B will innovate with a high probability in the first period.

3.3 Both firms need external finance

In this subsection we assume that not only firm A but also firm B has to be externally financed. Firm B applies for a loan at her own house bank, so there is competition in the banking sector. The information structure between the firms and the banks is the same as in the preceding section: because of the moral hazard problem a bank denies any follow-up financing if her client falls behind in the innovation game of the first period. Since this can happen to firm A in the case (01) and to firm B in the case (10) of the first period, there are two scenarii where we have monopolies in the product market of the second period.

The expected profits for firm B are now:

$$(16) \quad \begin{aligned} \Pi_B^e = & \theta_A \theta_B [\Pi_B^{11} - R_B^{11} + \gamma^{11} (\bar{\Pi}^{NW} - g(\mu^\circ) - R^{t=2})] \\ & + (1 - \theta_A)(1 - \theta_B) [\Pi_B^{00} - R_B^{00} + \gamma^{00} (\bar{\Pi}^{SE} - g(\mu^\circ) - R^{t=2})] \\ & + \theta_B (1 - \theta_A) [\Pi_B^{01} - R_B^{01} + 1 \cdot (\Pi^{Monopoly} - 0 - R^{Monopoly})] \\ & + \theta_A (1 - \theta_B) [\Pi_B^{10} - R_B^{10} + 0] - g(\theta_B) \end{aligned}$$

where γ denotes the refinancing probability. If firm B becomes a monopolist in the second period, the refinancing probability equals one. Moreover, in the absence of competition, she will then refrain from any engagement in R&D activities. If firm B fails to innovate in the first period while firm A is successful, firm B has to leave the market because the refinancing probability is zero.

Maximizing the expected profits (16) with respect to the innovation probability, we get the new condition for optimal R&D expenditures:

$$(17) \quad \begin{aligned} g'(\theta_B) = & \theta_A [\Pi_B^{11} - R_B^{11} + \gamma^{11} (\bar{\Pi}_B^{NW} - g(\mu^\circ) - R^{t=2}) - \Pi_B^{10} + R_B^{10} - 0] \\ & + (1 - \theta_A) [\Pi_B^{01} - R_B^{01} + \Pi^{Monopoly} - R^{Monopoly} - \Pi_B^{00} + R_B^{00} - \gamma^{00} (\bar{\Pi}_B^{SE} - g(\mu^\circ) - R^{t=2})] \end{aligned}$$

The financial contract between firm B and her bank resembles the one derived for firm A in the previous section (cf. equations (10) – (15)). The bank of firm B maximizes over expected repayments in both periods under the limited liability conditions, the incentive compatibility restrictions and the optimal R&D activities of firm B :

$$(18) \max V = \theta_A \theta_B \cdot R_B^{11} + \theta_A (1 - \theta_B) \cdot R_B^{10} + (1 - \theta_A) \theta_B \cdot R_B^{01} + (1 - \theta_A) (1 - \theta_B) \cdot R_B^{00} - F \\ + [\gamma^{11} \theta_A \theta_B + \gamma^{10} \theta_A (1 - \theta_B) + \gamma^{00} (1 - \theta_A) (1 - \theta_B)] (R^{t=2} - F) \\ + [\gamma^{01} (1 - \theta_A) \theta_B] (R^{Monopoly} - F)$$

subject to the limited liability constraints:

$$(19) \quad \Pi_B^{u,v} - g(\theta_B) \geq R_B^{u,v} \quad (u, v = 0, 1),$$

the condition for the optimal level of R&D activities:

$$(17) \quad g'(\theta_B) = \theta_A [\Pi_B^{11} - R_B^{11} + \gamma^{11} (\bar{\Pi}^{NW} - g(\mu^\circ) - R^{t=2}) - \Pi_B^{10} + R_B^{10} - 0] \\ + (1 - \theta_A) [\Pi_B^{01} - R_B^{01} + \Pi^{Monopoly} - R^{Monopoly} - \Pi_B^{00} + R_B^{00} - \gamma^{00} (\bar{\Pi}^{SE} - g(\mu^\circ) - R^{t=2})]$$

and the (binding) incentive compatibility constraints:

$$(20) \quad \Pi_B^{01} - R_B^{01} + 1 \cdot (\Pi^{Monopoly} - R^{Monopoly}) \geq \Pi_B^{00} - R_B^{00} + \gamma^{00} (\Pi^{Monopoly} - R^{Monopoly}),$$

$$(21) \quad \Pi_B^{00} - R_B^{00} + \gamma^{00} (\bar{\Pi}_B^{SE} - g(\mu^\circ) - R^{t=2}) \geq \Pi_B^{10} - R_B^{10} + \gamma^{10} (\bar{\Pi}_B^{SE} - g(\mu^\circ) - R^{t=2}).$$

The solutions to this optimal contract problem can be derived as follows:

Again we know that if firm B is the only firm in the first period that fails to innovate, the realized profits are insufficient to cover the required loan repayment, and therefore, the refinance probability γ^{10} will be zero. In all other cases of period one, the refinancing probabilities will be positive, but may be less than one. Because of the moral hazard problem, the repayments of the second period can only amount to the smallest profit possible.

The main difference is now the situation where we have a monopoly in the second-period. As far as the information structure is concerned, we assume that the bank still cannot observe product prices but will realize it when there is just one firm left in the market. In this case she will refinance her client with probability $\gamma^{01} = 1$, as she knows that the loan will be paid back with certainty. Since the bank has all the bargaining power she tries to extract as much of the monopoly profit of the firm as possible. But because of the competitiveness in the banking sector, the bank is unable to extract repayments higher than the amount of loan originally granted, F : If she would ask for repayments $R^{Monopoly}$ higher than F , the other bank would offer an one-period credit contract to firm B for slightly less. Therefore, repayments in the case of second-period monopoly $R^{Monopoly}$ must equal F .

Inserting these results into the incentive compatibility constraints and taking the limited liability conditions into account, we can derive the values for the refinancing probabilities and the repayments in the first and second periods. Again we have to distinguish between the two different cases:

$$\begin{aligned} \text{Case (3.3.1): } \gamma^{j0} &= 0 \text{ and } R_B^{10} = \Pi_B^{10} - g(\theta_B) \\ \gamma^{\theta0} = \gamma^{j1} = \gamma^{\theta1} &= 1 \text{ and } R_B^{00} = R_B^{11} = R_B^{01} = \bar{\Pi}_B^{SE} - g(\theta_B) \\ R_B^{t=2} &= \Pi_B^{SE-10} - g(\mu^\circ) \text{ and } R^{Monopoly} = F \end{aligned}$$

In this case the innovation probability μ° of the symmetric market situation in period two is higher than fifty percent, so that the refinancing probabilities $\gamma^{\theta0} = \gamma^{j1} = \gamma^{\theta1}$ will all equal one.

$$\begin{aligned} \text{Case (3.3.2): } \gamma^{j0} &= 0 \text{ and } R_B^{10} = \Pi_B^{10} - g(\theta_B) \\ \gamma^{\theta0} = \gamma^{11} &= \frac{\Pi_B^{00} - \Pi_B^{10}}{\bar{\Pi}_B^{SE} - \Pi_B^{10}} < 1 \text{ and } R_B^{00} = R_B^{11} = \Pi_B^{00} - g(\theta_B) \\ \gamma^{\theta1} &= 1 \text{ and } R_B^{01} = (1 - \gamma^{\theta0})(\Pi^{Monopoly} - F) + R_B^{00} \\ R_B^{t=2} &= \Pi_B^{SE-10} - g(\mu^\circ) \text{ and } R^{Monopoly} = F \end{aligned}$$

In this case the innovation probability μ° of the symmetric market situation in period two is less than fifty percent, the refinancing probabilities $\gamma^{\theta0} = \gamma^{j1}$ will therefore be smaller than one, and the first-period repayments for the innovation-leader R_B^{01} compared to the symmetric situations $R_B^{00} = R_B^{11}$ will be different.

Inserting these results into the condition for the optimal R&D expenditures (17), we see that the size of the monopoly profits has a negative impact on the slope and a positive impact on the intercept of the reaction function of firm B:

$$(17') \quad g'(\theta_B) = \theta_A \cdot \underbrace{[\dots - \Pi_B^{Monopoly} \dots]}_{<0} + \underbrace{[\dots + \Pi_B^{Monopoly} \dots]}_{>0}$$

If we do the same calculus for firm A, we can derive at the intersection of the R&D reaction functions the optimal R&D levels when both firms are credit-financed.

$$\text{Case (3.3.1)} \quad \theta_B^{FR**} = \frac{\Pi_B^{01} + (\Pi^{Mono} - F) - \Pi_B^{00} + \Pi_B^{10} - \bar{\Pi}_B^{SE}}{2r + \Pi_B^{01} + (\Pi^{Mono} - F) - \Pi_B^{11} - (\Pi_B^{00} - \Pi_B^{10}) - (\bar{\Pi}_B^{SE} - \Pi_B^{10})} = \theta_A^{FR**}$$

$$\text{Case (3.3.2)} \quad \theta_B^{FR**} = \frac{\Pi_B^{01} + \gamma^{\theta0}(\Pi^{Mono} - F) - \Pi_B^{00} + \Pi_B^{10} - \Pi_B^{11}}{2r + \Pi_B^{01} + \gamma^{\theta0}(\Pi^{Mono} - F) - \Pi_B^{11} - 2 \cdot (\Pi_B^{00} - \Pi_B^{10})} = \theta_A^{FR**}$$

Proposition 4: *If both firm A and firm B are financially restricted, their levels of optimal R&D activities in the first period decrease. Compared to the unrestricted case we have*

$$\theta_i^{FR**} < \theta_i^* \quad \text{for } i = A, B$$

as long as the potential monopoly profits are not extraordinarily high.

Graphically, we see that in contrast to *Figures 4&5* the reaction functions of the two credit-financed firms are symmetric again and that the optimal R&D expenditures in this Nash-equilibrium are (much) lower than in the self-financed equilibrium of *Figure 2*:

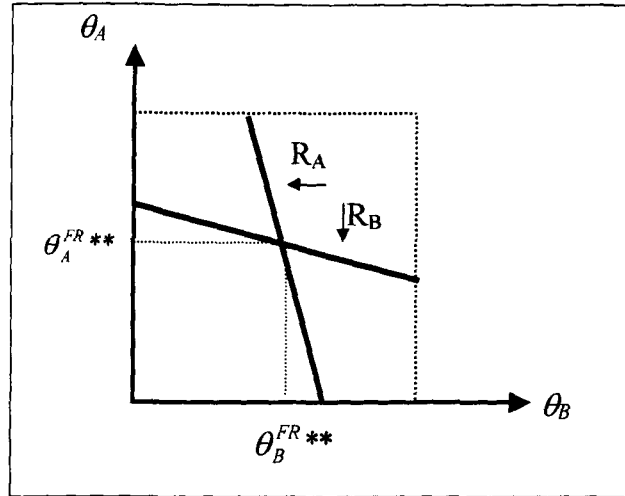


Fig. 6: R&D reaction functions when both firms are credit-financed
Case (3.3.1): $\gamma^{00} = \gamma^{11} = 1$

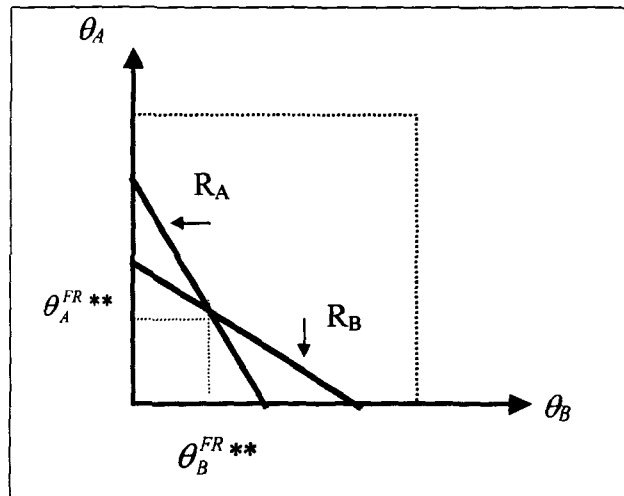


Fig. 7: R&D reaction functions when both firms are credit-financed
Case (3.3.2): $\gamma^{00} = \gamma^{11} < 1$

Second period R&D activities decrease as well because in the monopoly case, the firm will not engage at all in R&D activities. Overall welfare effects will therefore become negative when both firms are financially restricted.

3.4 Discussion and extensions

The main point of the analysis is that outside financing alters the innovative activities of both firms. Moreover, the optimal loan contract provides insufficient finance for the borrowing firm: Although expected net profits are positive in both periods, the firms in need of external finance will only obtain further financing if the actual first-period profits are not too low. The financial restriction therefore leads to product market inefficiency. This inefficiency cannot be overcome since there is no scope for renegotiation: a bank will never agree to further finance a firm that has fallen behind in the innovation-game of the first period due to the moral-hazard problem in the second period.

Another point of interest is the question (cf. BOLTON and SCHARFSTEIN (1990) or SNYDER (1996)) whether under the present assumptions predation would be possible. If the refinancing probabilities are equal to one, there is no chance for the self-financed firm (cf. 3.2) to prey upon her financially restricted rival. Only if the refinancing probabilities are less than one, the firm can attempt to reduce the profit opportunities for her rival by increasing the level of her own R&D activities.

In the present model we assume that the banks have all the bargaining power in financial contracting. Suppose instead that the bargaining power is on the side of the firms. Empirically this can be the case if financing is provided by federal funds, e.g. via the Reconstruction Loan Corporation (Kreditanstalt für Wiederaufbau) in Germany or via federal promotion programs for technology-based firms. In our model this alters the design of the optimal contract: The new objective function is given by the maximization problem of the firm subject to the zero-profit condition for the bank.⁸ As a consequence, the refinancing probabilities increase, especially when the competitor innovates and the own firm fails, the refinancing probabilities will now be greater than zero. As a result, market efficiency will rise.

4 Conclusion

We presented a simple model of multi-period innovation and market competition in which two firms operate with or without financial constraints. Innovations are induced by private R&D activities of the firms. A successful innovation project reduces marginal production costs. The cost-structure then determines the market position and hence the profit situation of the firm.

If a firm is financially constrained, she applies for a bank loan in order to cover the fixed production costs. As for the information structure we assumed that the bank is unable to

⁸ See STADLER (1997) for an explicit theoretical treatment.

observe the results of the innovation projects and therefore has no information about the actual profit situation of the firm.⁹ The bank designs an optimal, incentive-compatible loan contract in which repayments are based on reported profits. Loan repayments in the first period are higher than the amount of loan received, whereas repayments in the second period are lower because of the moral hazard problem.

The financial restrictions of the firms have the following implications for the innovation activities and the market structure:

If only one firm is externally financed, R&D activities of the leveraged firm will decrease while R&D activities of the unleveraged rival will increase in the first period. Furthermore, product prices of the leveraged firm will be higher and product prices of the unleveraged rival will presumably be lower than in the self-financing case. Welfare effects of the first period could therefore be positive. But if the unleveraged firm becomes a monopolist in the second period and raises her prices up to the consumers' reservation value \bar{s} , overall welfare effects will become negative.

If both firms need external financing, R&D activities will definitely decrease. The financial contracts between the firms and their house bank imply that large parts of the innovation gains are transferred to the banks. So the firms have little incentives to engage in R&D activities. Moreover, the likelihood for a monopoly in the second-period will increase. Since R&D activities in this case are zero, overall welfare will decline

Our model serves to analyze the innovative behavior of established firms when interactions between the financial and the product markets are taken into consideration. When credit markets are imperfect due to asymmetric information, financial restrictions reduce the innovative activities of firms which finally results in a loss of social welfare.

⁹ An equivalent assumption is that firms are able to embezzle money before the bank can observe realized profits.

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