FINANCIAL STRUCTURE, RISK MANAGEMENT,
AND TECHNOLOGICAL FLEXIBILITY IN A STRATEGIC CONTEXT*

by

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Abstract

We study the interactions between debt/equity financing and strategic (duopoly) technological flexibility choices of firms facing a possibility of costly bankruptcy. We show that a firm’s level of debt financing or financial hardship is an important determinant of the level and type of investment it chooses to make, either a less costly inflexible technology or a more expensive flexible technology. We show that the level of financial hardship has a non-monotonic effect: as the level of equity financing increases, the choice of technology may change and the level of investment may first increase and then decrease or vice-versa, depending on the differential investment cost, the bankruptcy cost, and whether or not the less costly technology is the best reply for an all equity firm. In some cases, more flexibility reduces the risk of costly bankruptcy, while in other cases, it is inflexibility. Hence, the choice of technology is an element of real risk management. We show also that the level of external financing (debt) may be used strategically in a non-cooperative tacitly collusive way to increase the expected profits of both firms, that a firm may use debt as a commitment device to increase its own expected profit, and that higher bankruptcy costs may be beneficial to both firms.

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1 Introduction

We consider in this paper the relationship between corporate finance and technological choices made by firms, that is, the interrelated determination of capital structure (equity versus debt financing), the type of technology chosen by firms, the level of capital expenditures, and the relative performance of the firms in product markets. Our paper must be seen as a contribution to the literatures on the joint determination of real and financial decisions (Dammon and Senbet 1988, Leland 1998), on the strategic effects of financial structure on real decisions in imperfectly competitive contexts (Chevalier 1995, Phillips 1995, Kovenock and Phillips 1995), on competitive equilibrium outcomes as opposed to decision theoretic ones (Brander and Lewis 1986, 1988, Maksimovic and Zechner 1991, Williams 1995, Fries, Miller and Perraudin 1997), and on the relationship between a firm’s capital expenditure and financial hardship (Kaplan and Zingales 1997 and 2000, Cleary 1999, Fazzari, Hubbard and Petersen 2000). As Mackay and Phillips (2003) states: “Despite extensive financial structure research since Myers (1984) and Harris and Raviv (1991) surveyed the literature, important puzzles remain. The importance of industry to firm financial structure and the simultaneity of financial and real-life decisions are two such related puzzles.”

Most contributions assume a given technology, more precisely a given, in some cases uncertain, production cost function for the firm. But as emphasized by Stigler (1939), firms have some degrees of freedom in choosing their cost functions. In this spirit, Boyer and Moreaux (1997) show that a way to commit to a strategy in the product competition stage is to choose a relatively inflexible technology. The profitability trade-off in this case stems from the fact that a firm choosing a relatively inflexible technology can, if the capacity of the inflexible technology is relatively low [high] relative to the expected size of the market, reduce the market share of its rival in states of low [high] demand but cannot fully exploit [but shuts down and goes bankrupt in] the states of high [low] demand.

We consider two main types of technologies, the dedicated but inflexible technologies and the flexible ones, the latter being more capital intensive. According to business commentators, flexibility has become the Holy Grail in the ‘new’ economy where developments in globalization, information technologies and flexible systems (Flexible Manufacturing Systems for instance)
have jointly made the markets significantly more volatile. The choice of flexibility could be achieved through reengineering, outsourcing, downsizing, focusing on core competencies, investing in computer controlled flexible technologies, empowering key individuals with specific human capital, and/or designing more powerful incentive schemes and corporate governance rules to ensure better congruence of interests and information sharing throughout the firm.¹

Our main results are the following. When an all equity firm, facing an inflexible competitor, is better off choosing a less costly inflexible [more costly flexible] technology, then this choice remains the best option as the firm’s level of debt financing increases if the differential investment cost between flexible and inflexible technologies is large [small]. Otherwise, the more costly flexible [less costly inflexible] technology becomes the firm’s best option for intermediate levels of debt while an inflexible [flexible] technology is again the firm’s best option for high level of debt financing. Hence, the level of financial hardship (debt) has a non-monotonic effect on the type and level of investment: as the level of debt financing decreases, the level of investment may first increase and then decrease (or vice-versa) depending on the differential investment cost and on whether or not the less costly inflexible technology is the best reply for an all equity firm. Moreover, we show that the level of external financing (debt) may be used strategically in a non-cooperative tacitly collusive way to increase the expected profits of both firms. A firm may also use debt as a commitment device in order to increase its own expected profit. Finally, we show that firms may benefit from larger bankruptcy costs because those costs modify their respective technological best reply functions and may lead them to more profitable non cooperative technological equilibria.

More specifically, we examine a duopoly context where the capital structures of firms are first considered exogenous and later endogenous. When considered exogenous, the debt financing conditions or contracts of firms depend on the technological equilibrium configuration which emerges in the industry as capital structures and technologies determine the relative performance of firms in the product markets, including the likelihood of bankruptcy. When considered en-

¹Business International (1991) claims that the search for flexibility is the all-inclusive concept allowing an integrated understanding of most if not all developments in management theory, especially the need for more concerted effort in introducing flatter organizational structures, investing in automated manufacturing, creating strong but malleable alliances, etc. In decision theoretic terms, this means harnessing and exploiting the supermodularity features of the set of strategies. Supermodularity implies that adopting one of the strategies increases the profitability of adopting the other ones. See Milgrom and Roberts (1990).
domedous, the capital structures of both firms, the conditions of their debt financing contracts, and their respective type and level of technology investment are all determined simultaneously in a first stage followed by Cournot competition outcomes in a second stage. In such a context, flexibility may have both advantages and disadvantages. Therefore, choosing a proper flexibility level in a corporation raises subtle strategic issues, often neglected in the management literature. A flexible manufacturing system capable of producing a wider scope of products will typically be more expensive than a dedicated one, in terms of capital expenditures per se, the cost of coherency in the internal organization of the firm, and the cost of managing its relations and workflows with suppliers and customers. The evaluation of the proper flexibility spectrum in a firm, whether this flexibility comes from technological, organizational or contractual characteristics, requires an evaluation of the trade-off between the value and cost of changes in the real options portfolio so created, in the probability of bankruptcy, in the probability of being preempted in significant markets, and of changes in the behavior of competitors, actual and potential, who may be more or less aggressive towards the firm depending on its level of technological flexibility and financial liquidity. The analysis of these issues requires modeling strategic competition with explicit variables for flexibility and liquidity.

One expects that the debt level can change the technological flexibility choice of a firm since the latter modifies in an important way the distribution of cash flows over the different states of nature. Since the type of technology together with the cash flows generated will affect the probability of bankruptcy, we must consider that the financial and technological choices of a firm are interdependent and simultaneously determined, at least in part. With bankruptcy costs, debt improves the competitive position of the firm in some contexts but is a source of weakness in others. This implies that debt may be used strategically.\footnote{See Gerwin (1982, 1993), Mensah and Miranti (1989), Vives (1989), Milgrom and Roberts (1990) and Boyer and Moreaux (1997) for convincing industrial examples.}

\footnote{Brander and Lewis (1986, 1988) show that, in an oligopolistic market with demand uncertainty, debt and limited liability induce firms to take more risky positions as suggested previously by Jensen and Meckling (1976). By increasing its debt level, a firm can move upwards its best reply function in the product competition stage thereby decreasing the equilibrium production level of its rival: debt has a strategic value. There is an important literature on this topic. Maksimovic (1988) analyses the impact of debt on the possibility to sustain collusion. Poitevin (1989, 1990) argues that debt may allow the signaling of low production cost. In Bolton and Scharfstein (1990), debt decreases the probability of survival and therefore increases the probability that rivals will prey on it. In a two period model in which debt is repaid at the end of the last period, Glazer (1994) shows that debt is pro-competitive in the second period but allows some kind of tacit collusion in the first period because an increase in the rival’s profit decreases its residual debt and makes it less aggressive in the last period. Considering}
Our model, analysis and results are also related to the literature on risk management. There are four main reasons why managers may want to engage in corporate risk management: First, risk management, in reducing the volatility of taxable income, can reduce expected taxes when corporate taxation is progressive; Second, risk management may alleviate agency problems through for instance a reduction in the volatility of results, thereby making those results more informative on the performance of management and allowing a higher congruency between the respective interests of shareholders and managers; Third, the stabilization of internal liquidity and cash flows reduces the disruptive impacts of having to raise costly external financing for new or ongoing R&D and other strategic projects as well as for the capacity to exercise real options and for launching or counteracting preemptive moves; Finally, the reduction of volatility, in particular downside risks (or the VaR – value at risk), allows a reduction in the expected cost – probability and loss – of financial distress and bankruptcy (the costs of bankruptcy protection, loss of goodwill, management diversion, deadweight loss, legal measures, and other reorganization efforts) which may represent a significant share of assets. The risk management literature is centered on alleviating risks through financial instruments. We stress in this paper the role of the firm’s technological choice as a real instrument of risk management.

The paper is organized as follows. We present the model in section 2. We derive in section 3 the profit functions of the firms for given technologies and we characterize the competitive debt contracts. In section 4, we study the impact of debt on technological flexibility choices. In section 5, we analyze the strategic value of debt and we characterize the joint determination of capital structures and technological investments. We conclude in section 6 with further comments on the empirical implications of our results.

a Bertrand competition model, Showalter (1995, 1999) derives that the strategic effect of debt depends on the type of uncertainty (cost versus demand) in the output market: if costs are uncertain, firms do not leverage but, if demand conditions are uncertain, firms carry positive strategic debt levels in order to soften competition. In a similar framework, Schnitzer and Wambach (1998) investigate the choice between inside and outside financing by risk-averse entrepreneurs who produce with uncertain production costs. Parsons (1997), expanding Brander and Lewis (1988) by allowing corner solutions, shows that firms may initially have an incentive to decrease output levels if they take on more debt. Hughes, Kao and Mukherji (1998) show that the possibility to acquire and share information may invalidate Brander and Lewis (1986) result. Dasgupta and Shin (1999) show that, when one firm has better access to information, leverage may be a way for the rival firm to free-ride on the firm’s information.

2 The model

The inverse demand function is assumed to be linear: \(^5\)

\[ p = \max(0, \alpha - \beta Q) \]

where \( Q \) is the aggregate output and \( \alpha \) is a random variable taking value \( \alpha_1 \) with probability \( \mu \) and \( \alpha_2 \) with probability \( 1 - \mu \), where \( \alpha_2 > \alpha_1 \). Firms choose between two technologies: one is inflexible (\( i \)) and the other is flexible (\( f \)). An inflexible firm either produces \( x \), where \( x \) is the exogenous capacity, or shuts down. A flexible firm can choose any positive level of production. The two technologies have the same average operating cost \( c \), but their capital expenditures (product design costs, land purchases, plant construction costs, fixed marketing cost, and so on) differ: it is equal to \( K \) for \( i \) and to \( K + H \) for \( f \), with \( H \geq 0 \). Hence, a firm choosing the flexible technology incur larger capital expenditures.

Initially, entrepreneur \( h \in \{1, 2\} \) has an equity capital of \( A_h \) to be invested in his firm. This capital level is exogenous, an assumption we will relax in section 5. If \( A_h \) is less than \( K \) or \( K + H \), the entrepreneur must raise external capital. This external capital could be raised through external equity or debt. Both sources of external capital could be used here but we will assume that it is raised through borrowing.\(^6\) A debt contract will specify a level of repayment \( R \) independent of the level of profit but dependent on the observable technological choices of both firms. If a firm is unable to repay \( R \), it goes bankrupt and its gross profit is seized by the bank. We assume also that the banking sector is perfectly competitive: for each loan, the expected repayment is equal to the payoff the bank can obtain from lending at the riskless interest rate, normalized at zero.

The entrepreneurs have limited liability but bankruptcy generates a non-monetary cost for an entrepreneur since bankruptcy sends a bad signal on his management skills, making it harder for him to find a new job or to borrow new capital to finance another project. This cost is assumed to have a monetary equivalent value \( B \), independent of the level of default.\(^7\)

\(^5\)Demand linearity and the other specific assumptions are made only to get explicit tractable equilibrium solutions. The reader will understand that those assumptions could be relaxed at the cost of more complexity and less transparency in the results.

\(^6\)External financing is overwhelmingly raised through debt issuance in all G-7 countries except France. See Rajan and Zingales (1995), Table IV.

\(^7\)In the case of external equity financing, the entrepreneur would similarly suffer from a loss of reputation in
The two entrepreneurs begin the competition game with observable amounts of equity $A_1$ and $A_2$. The timing of the game is as follows. In the first stage, each entrepreneur chooses his technology and negotiates his loan conditions, and both entrepreneurs do it simultaneously. We model the simultaneous determination of the four decision variables as follows: first, entrepreneurs simultaneously negotiate debt contracts (level of debt and repayment) as functions of the technological configuration to emerge in the industry and second, they choose simultaneously their respective technology. In this way, the two choices (technology and debt contract) of the two entrepreneurs are determined simultaneously in stage 1. Clearly, debt contracts are not in practice a function of the technological configuration of the industry. This modeling strategy must be understood as a reduced form representation of the “business plan” typically required by banks. In preparing its business plan, a firm will implicitly refer to the type of technology and level of capacity installed by other firms in the industry and to the volatility of market conditions in order to credibly convince the bank of the realism of its business plan (that is, the level of profit it is likely to make in different scenarios or states) and therefore of the risk it represents. Hence the debt contracts and the technologies or flexibility levels can be considered as being chosen simultaneously within a firm and across firms. In the second stage, the entrepreneurs observe the level of demand (that is, whether $\alpha$ equals $\alpha_1$ or $\alpha_2$) and they engage in Cournot competition. From the outcome of the second stage, firms realize profits and repay debt or go bankrupt.

This model is a simple tractable strategic competition model capturing the interdependence between corporate finance (internal liquidity, equity and debt financing) and firms’ technological investments (both the type of investment, that is flexibility, and the level of capital expenditures), under significant bankruptcy cost and demand uncertainty.

3 The expected profits as functions of technological choices

Debt levels play a crucial role in the product competition stage because it determines the probability of bankruptcy. We characterize in this section the debt threshold, over which the firm cannot repay its debt in the bad state of demand, as a function of technological configurations.

addition to the dilution of his ownership.
We will assume (without loss of generality) that in the high state of demand (\(\alpha_2\)), both firms produce and avoid bankruptcy at the Cournot stage of the game whatever their technological choices, that is \(x < (\alpha_2 - c)/2\beta\), and that in the state of low demand a firm with low (close to 0) equity goes bankrupt whatever its technology.\(^8\)

The conditions under which a firm goes bankrupt in the low state of demand depends on how low the low state of demand (or size of the market) is relative to the capacity of the inflexible technology. To facilitate the analysis, it will prove useful to regroup the four exogenous parameters \(\omega = (\alpha_1, c, \beta, x)\) into three sets \(\Omega_s\). The second stage Cournot equilibrium profits over operating costs, as functions of the technological choices of the firms, are derived in Appendix A.

- \(\Omega_1 \equiv \{\omega \mid x < (\alpha_1 - c)/2\beta\} \equiv \{\omega \mid \alpha_1 > 2\beta x + c\}\): The capacity \(x\) of the inflexible technology is small relative to the size of the market under low demand implying that even under the low market state, both firms produce at the second stage of the game for any technological choices.

- \(\Omega_2 \equiv \{\omega \mid (\alpha_1 - c)/2\beta < x < (\alpha_1 - c)/\beta\} \equiv \{\omega \mid \beta x + c < \alpha_1 < 2\beta x + c\}\): The capacity \(x\) is intermediate relative to the size of the market under low demand so that, when demand is low, technological configurations \((f, f)\) and \((f, i)\) imply the same equilibria as when \(\omega \in \Omega_1\), whereas configuration \((i, i)\) implies that one firm shuts down and the other obtains its monopoly profit.

- \(\Omega_3 \equiv \{\omega \mid (\alpha_1 - c)/\beta < x\} \equiv \{\omega \mid \alpha_1 < \beta x + c\}\): The capacity \(x\) is large relative to the size of the market under low demand so that, when demand is low, technological configuration \((f, f)\) implies the same equilibria as when \(\omega \in \Omega_1 \cup \Omega_2\), \((f, i)\) implies that the inflexible firm shuts down whereas the flexible firm enjoys a monopoly profit level, and \((i, i)\) implies that both firms shut down.

For \(t, t' \in \{i, f\}\) and \(\Omega \in \{\Omega_1, \Omega_2, \Omega_3\}\), we shall denote by \(\pi_k(t, t', \Omega)\) the profit of a firm with technology \(t\) facing a rival with technology \(t'\) when \(\omega \in \Omega\) and \(\alpha = \alpha_k \in \{\alpha_1, \alpha_2\}\), and by \(E\Pi(t, t', \Omega)\) the first stage reduced form expected profit of a firm with technology \(t\) as a function

\(^8\)In other words, the level of profit over variable cost a firm makes in the low state of demand is always less than the cost \(K\) or \(K + H\) of the technologies. These simplifying assumptions allow us to concentrate on the more interesting cases.
of the industry technological configurations and the parameter set $\Omega$. The debt threshold, over which the firm goes bankrupt, is simply the profit level $\pi_1(t, t', \Omega)$.

### 3.1 Financial contract and expected profit of a flexible firm

When demand is low, the gross profit of a flexible firm is equal to $\pi_1(f, t', \Omega)$ which defines the debt threshold so that if debt $D$ is less than $\pi_1(f, t', \Omega)$, the firm repays the bank and avoids bankruptcy. Given the assumption that the banking sector is perfectly competitive (with a best alternative rate of interest of 0), the repayment $R_h$ is then simply equal to the amount borrowed $K + H - A_h$. On the other hand, if the firm’s debt is larger than $\pi_1(f, t', \Omega)$, the firm goes bankrupt when demand is low. In this bad state of the market, the firm repays only its gross profit as the bank seizes the firm’s assets. So in the good state, the firm must repay an amount $R_h$ such that the expected return on that loan is equal to zero, that is $\mu \pi_1(f, t', \Omega) + (1 - \mu) R_h = K + H - A_h$. Hence, $R_h$ as a function of $(f, t')$ is given by:

$$R_h = \frac{1}{1 - \mu} [K + H - A_h - \mu \pi_1(f, t', \Omega)].$$

We see from (1) that the financial contract negotiated between firm $h$ and any bank is a function of the technologies chosen by both firms and of the equity of firm $h$. We can obtain the expected profit as follows. For low debt levels, the firm never goes bankrupt and its expected profit is $\mu \pi_1(f, t', \Omega) + (1 - \mu) \pi_2(f, t', \Omega) - (K + H)$. For large debt levels, the firm goes bankrupt if demand is low; its expected profit is $(1 - \mu) [\pi_2(f, t', \Omega) - R_h] - \mu B - A_h$ where $R_h$ is now given by (1). Thus, we obtain the expected profit of a flexible firm facing a competitor with technology $t' \in \{i, f\}$:

$$E\Pi(f, t', \Omega) = \begin{cases} E\Pi(f, t', X), & \text{if } K + H - A_h \leq \pi_1(f, t', \Omega) \\ \tilde{E}\Pi(f, t', X) - \mu B, & \text{if } K + H - A_h > \pi_1(f, t', \Omega) \end{cases}$$

where $K + H - A_h$ is the amount borrowed by the firm and $\tilde{E}\Pi(f, t', \Omega)$ is the expected profit when the firm’s debt is low enough to avoid going bankrupt:

$$\tilde{E}\Pi(f, t', \Omega) = [\mu \pi_1(f, t', \Omega) + (1 - \mu) \pi_2(f, t', \Omega)] - (K + H).$$

The difference between the two profit levels in (2) is the expected bankruptcy cost. The expressions for $\pi_k(\cdot)$ and $\tilde{E}\Pi(\cdot)$ are derived in Appendix A.
3.2 Financial contract and expected profit of an inflexible firm

For the inflexible firm, we must distinguish two cases, a first case where either \( \omega \in \Omega_1 \cup \Omega_3 \) and \( t' \in \{i, f\} \) or \( \omega \in \Omega_2 \) and \( t' = f \), and a second case where \( \omega \in \Omega_2 \) and \( t' = i \). In the former case, the gross profit of an inflexible firm is equal to \( \pi_1(i, t', \Omega) \) when demand is low so that if its debt level \( D = K - A_h \) being smaller than this gross profit, it avoids bankruptcy and its repayment is simply \( K - A_h \). Otherwise it goes bankrupt in the low state of demand and the zero expected payoff condition of the banking contract takes the form \( \mu \pi_1(i, t', \Omega) + (1 - \mu) R_h = K - A_h \), implying that:

\[
R_h = \frac{1}{1 - \mu} [K - A_h - \mu \pi_1(i, t', \Omega)].
\] (4)

Its expected profit is therefore given by

\[
\mathbb{E} \Pi (i, t', \Omega) = \begin{cases} 
\mathbb{E} \Pi (i, t', X), & \text{if } K - A_h \leq \pi_1(i, t', \Omega) \\
\mathbb{E} \Pi (i, t', X) - \mu B, & \text{if } K - A_h > \pi_1(i, t', \Omega)
\end{cases}
\] (5)

where

\[
\mathbb{E} \Pi (i, t', \Omega) = \mu \pi_1(i, t', \Omega) + (1 - \mu) \pi_2(i, t', \Omega) - K.
\] (6)

If \( \omega \in \Omega_2 \) and \( t' = i \), only one firm produces when demand is low. We assume that the producing firm is determined randomly with equal probability. Hence we must define two debt thresholds in this case: 0 if the firm does not produce and \( \pi_1(i, i, \Omega_2) \) if it produces. The producing firm goes bankrupt when demand is low if \( K - A_h > \pi_1(i, i, X_2) \). The repayment \( R_h \) to be paid in the good state of demand is then given by

\[
R_h = \begin{cases} 
\frac{1}{1 - \mu/2} (K - A_h), & \text{if } K - A_h < \pi_1(i, i, X_2) \\
\frac{1}{1 - \mu} \left( K - A_h - \frac{1}{2} \mu \pi_1(i, i, \Omega_2) \right), & \text{otherwise}
\end{cases}
\] (7)

Making use of (7), we obtain the expected profit which is the same for both firms:

\[
\mathbb{E} \Pi (i, i, X_2) = \begin{cases} 
\mathbb{E} \Pi (i, i, \Omega_2), & \text{if } K - A_h \leq 0 \\
\mathbb{E} \Pi (i, i, \Omega_2) - \frac{1}{2} \mu B, & \text{if } 0 < K - A_h \leq \pi_1(i, i, \Omega_2) \\
\mathbb{E} \Pi (i, i, \Omega_2) - \mu B, & \text{if } \pi_1(i, i, \Omega_2) < K - A_h
\end{cases}
\] (8)

where

\[
\mathbb{E} \Pi (i, i, X_2) = \mu \frac{1}{2} \pi_1(i, i, \Omega_2) + (1 - \mu) \pi_2(i, i, \Omega_2) - K.
\] (9)
4 The impact of equity on investments in technology

A firm’s borrowing cost, expected profit and probability of bankruptcy are determined by the technological configuration of the industry and its own level of equity. To characterize the impact of internal liquidity on the technological equilibrium in an industry, we must first determine its impact on the technological best reply functions.

A firm’s debt level is given by the difference between the cost of the technology it chooses, either $K$ or $K + H$, and its internal equity or liquidity level $A_h$. For a given technological configuration, a firm’s expected profit is independent of the debt level provided that the firm can make the repayment when demand is low (debt is then riskless). When debt is higher than the firm’s profit level under low demand, the expected net profit is reduced by the expected bankruptcy costs. If there is no bankruptcy cost, we find the well known Modigliani and Miller (1958) result: the capital structure of the firm is irrelevant, a firm’s technological investment choice being independent of its capital structure. But with significant bankruptcy costs, the need to borrow may induce the firm to choose a technology different from the technology it would choose otherwise.

Hence, two elements will be crucial in this analysis, first the level of bankruptcy cost $B$ and second the firm’s needed level of borrowing which will depend on both its capital expenditures (technology) and its equity or liquidity level $A$. Large values of $B$ may be expected to induce firms to opt for more flexibility and reduced borrowing in order to avoid costly bankruptcy in the bad state of demand. But these options may be in conflict, the more so the larger $H$ is since a large $H$ increases the borrowing needs of the flexible firm and therefore the possibility that it will go bankrupt.

The critical levels of $B$ and $H$ will depend on $\omega$, that is on the capacity of the inflexible technology relative to the size of the market under low demand (see Appendix B). When $\Omega \in \{\Omega_1, \Omega_3\}$, $H$ is considered large [small] if it is larger [smaller] than the profit differential under low demand $\pi_1(f, i, \Omega) - \pi_1(i, i, \Omega)$ while $B$ is considered large [small] if $\mu B$ is larger [smaller] than the absolute value of the profit differential of the technologies for an all equity firm $|\bar{E}\Pi(i, i, \Omega) - \bar{E}\Pi(f, i, \Omega)|$. When $\Omega = \Omega_2$, $H$ is large if it is larger than the profit level $\pi_1(f, i, \Omega_2)$, small if $\mu B < |\bar{E}\Pi(i, i, \Omega_2) - \bar{E}\Pi(f, i, \Omega_2)|$. When $\Omega = \Omega_1$, $H$ is large if it is larger than the profit level $\pi_1(f, i, \Omega_1)$, small if $\mu B < |\bar{E}\Pi(i, i, \Omega_1) - \bar{E}\Pi(f, i, \Omega_1)|$.

The result can be seen directly from expressions (12) to (16) in Appendix B.
it is smaller than $\pi_1(i, i, \Omega_2)$ and intermediate if it is in between those two profit levels; in the first two cases, $B$ is large if $\mu B$ is larger than $|\tilde{\Pi}(i, i, \Omega) - \tilde{\Pi}(f, i, \Omega)|$ as before while in the last case $B$ is large if $\mu B$ is larger than twice that value. With these benchmarks in mind, we can characterize the best response to inflexibility and flexibility.

To simplify the presentation of the results and to concentrate on the cases where the capital structure of the firm does matter, we will assume from now on that the bankruptcy cost $B$ is always ‘large’.

4.1 The best response to inflexibility ($t' = i$)

Suppose that a firm’s competitor has chosen the inflexible technology. To determine the firm’s best response, we must determine the value of its expected profit differential $\Pi(i, i, \Omega) - \Pi(f, i, \Omega)$, which for each $\Omega \in \{\Omega_1, \Omega_2, \Omega_3\}$ is a step function of the bankruptcy cost and the firm’s equity or internal liquidity $A$.

If a firm’s equity or liquidity is relatively low, it goes bankrupt when demand is low whatever its technology.\(^{10}\) Hence the firm cannot avoid bankruptcy by switching technologies. If a firm’s equity or liquidity is relatively large, it never goes bankrupt. Hence the technological best response in these two cases will be the same. For intermediate levels of equity, whether or not a firm goes bankrupt in the low state of demand will depend on its technology. If $H > \pi_1(f, i, \Omega) - \pi_1(i, i, \Omega)$ and $K - \pi_1(i, i, \Omega) < A_h < K + H - \pi_1(f, i, \Omega)$, the firm goes bankrupt in the low state of demand if and only if it has a flexible technology. If $H < \pi_1(f, i, \Omega) - \pi_1(i, i, \Omega)$ and $K + H - \pi_1(f, i, \Omega) < A_h < K - \pi_1(i, i, \Omega)$, the firm goes bankrupt in the low state of demand if and only if it has an inflexible technology. The formal characterization of a firm’s technological best reply to the technological choice of its competitor is given in Appendix B.

From (2) and (5), we obtain the following proposition.

**Proposition 1** When inflexibility [flexibility] is the best response to inflexibility for an all equity firm, it remains the best response for all levels of equity if $H$ is large [small]; otherwise, inflexibility [flexibility] is the best response for low and high levels of equity financing while flexibility

\(^{10}\)This is due to our simplifying assumption that the minimum level of equity necessary to avoid bankruptcy is positive in all cases. See Appendix B.
[inflexibility] becomes the best response for intermediate levels. In the latter case, the level of investment is the same for low and high levels of equity financing but it is smaller [larger] for intermediate levels: the relation between the level of investment and the level of equity or internal liquidity is therefore non-monotonic.

When inflexibility is the best response to inflexibility for an all equity firm, that is \( \hat{E}\Pi(i, i, \Omega) \leq \hat{E}\Pi(f, i, \Omega) \), it will be the best response for all levels of equity financing if the incremental cost \( H \) of switching to a flexible technology is large,\(^{11}\) in which case it is not appropriate to invest in the more costly technology and give up profitable market opportunities simply to try to avoid bankruptcy since, from (12) and (14) in Appendix B, bankruptcy is then more likely with a flexible technology. However, when the differential investment cost is not so large, then the firm will prefer giving up some market share and profit in order to avoid the costly bankruptcy. From (13), (15) and (16), bankruptcy will occur in the low state of demand if the firm, endowed with an intermediate level of equity financing, has the inflexible technology but not if it has the flexible technology.\(^{12}\) Hence the firm will switch to the more costly flexible technology in those cases.

Similarly for the case where flexibility is the best response to inflexibility for an all equity firm,\(^{13}\) the firm, facing a large differential investment cost \( H \), will prefer giving up some market share and profit in order to avoid the costly bankruptcy which, from (12), (14) and (15), will occur in the low state of demand if the firm’s level of equity financing is intermediate and the firm has the flexible technology but not if it has the inflexible one. Hence the firm will switch to the less costly inflexible technology in those cases.

### 4.2 The best response to flexibility (\( t' = f \))

Let us define \( A(i, f, \Omega) \) and \( A(f, f, \Omega) \) for \( \Omega \in \{\Omega_1, \Omega_2, \Omega_3\} \) as the minimum level of equity required to avoid bankruptcy when a firm chooses respectively the inflexible and the flexible

\(^{11}\)The precise bounds are given in Appendix B.

\(^{12}\)As shown by (13), (15) and (16), the interval for which the level of equity financing is considered ‘intermediate’ depends on the case considered.

\(^{13}\)This case is not explicitly developed here but it follows steps similar to those in Appendix B with reversed inequalities.
technology whereas the other firm is a flexible firm, that is:

\[ A(i, f, \Omega) = K - \pi_1(i, f, \Omega) \quad \text{and} \quad A(f, f, \Omega) = K + H - \pi_1(f, f, \Omega). \]  
(10)

An argument similar to the argument developed for characterizing the best response to inflexibility leads to the following proposition.

**Proposition 2** When flexibility [inflexibility] is the best response to flexibility for an all equity firm, it remains the best response for all levels of equity financing if \( H \) is small [large]; otherwise, flexibility [inflexibility] is the best response for low and high levels of equity financing while inflexibility [flexibility] becomes the best response for intermediate levels. Again, the relation between the level of capital expenditures and equity financing or internal liquidity is non-monotonic.

When flexibility is the best response to flexibility for an all equity firm, the best response will change to inflexibility for intermediate levels of equity financing, when the investment saving from switching to the less costly inflexible technology is large, before reswitching to flexibility for low levels of equity. The switch to inflexibility occurs because the firm finds profitable to save on capital expenditures and avoid a costly bankruptcy even if it then gives up some profitable market opportunities. Hence, the level of investment is a non-monotonic function of the internal liquidity level, the firms facing severe financial constraints or no constraint at all investing more than the firms facing ‘intermediate’ financial hardship. When inflexibility is the best response to flexibility for an all equity firm, a switch occurs to a flexible technology when the differential investment cost is small and the firm faces intermediate financial hardship. In such cases, the larger capital expenditures are more than compensated by the avoidance of bankruptcy if demand is low. Hence, the level of capital expenditures is again a non-monotonic function of the level of equity financing, the firms facing severe financial constraints or no constraint at all investing less than the firms facing ‘intermediate’ financial hardship.

### 4.3 Equilibrium technological investments and configurations

Rather than proceed with a complete characterization of equilibrium technological configurations one can derive from the above best reply functions, we present in this section numerical examples which will prove sufficient to show how equilibrium technological configurations in the industry
emerge from debt or equity financing levels of the firms. In the first three examples, we use the same parameter values, except for $\alpha_1$, in order to illustrate the impact of moving from $\Omega_1$ to $\Omega_2$ to $\Omega_3$:

$$\mu = 0.5, \quad \alpha_2 = 15, \quad x = 3, \quad \beta = 1, \quad c = 0.2, \quad K = 5.5, \quad H = 3, \quad B = 6.$$ 

**Example 1**: $\alpha_1 = 6.3 \ (\omega \in \Omega_1)$

We consider first a common equity financing level for both firms, that is $A_h = A$ for $h = 1, 2$ (Figure 1) before looking at the more general case of asymmetric levels (Figure 1').

**FIGURE 1**

Equilibrium technological configurations in example 1, $\omega \in \Omega_1$:

in $Z$, $(f, i)$ or $(i, f)$; in $Y$, $(f, f)$ and $(i, i)$.

If the common equity level is relatively high ($A \geq 6.1$), in particular if it can cover the cost of both technologies ($A \geq 8.5$), both firms choose the more costly flexible technology in equilibrium. When firms have such high equity levels, choosing flexibility is a dominant strategy. This technology allows firms to take advantage of the opportunities offered when demand is high. Firms adopt the flexible technology in spite of its two disadvantages: a larger level of capital expenditures and a lower profit when demand is low. If $5.2 < A < 6.1$, there are two Nash equilibria in which both firms choose the same technology, either the flexible or the inflexible one. With such levels of equity financing, firms may need to raise debt financing: flexibility remains the best reply to flexibility but inflexibility becomes the best reply to inflexibility.

When its rival chooses an inflexible technology, a flexible firm cannot repay its debt in the bad state of demand. But it can eliminate the risk of bankruptcy by switching to the inflexible technology which being cheaper allows a reduction in the amount borrowed, but at the cost of a reduction in profit when demand is high. This effect explains the change from $f$ to $i$ in the best reply function to inflexibility. Another equilibrium $(i, i)$ appears. In this interval of

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14 The examples are worked out in detail in Appendix C.
equity financing levels, the firms may fall into a *flexibility trap* since \((i, i)\) is more profitable for both firms (see Appendix C). If \(4.37 < A < 5.2\), the unique equilibrium is again \((f, f)\). At such equity financing levels, a flexible firm facing an inflexible firm cannot repay its debt when demand is low, but a change in technology would not eliminate the probability of bankruptcy and therefore the previous effect disappears and both firms choose again the more expensive flexible technology. If \(0.85 < A < 4.37\), the equilibrium is asymmetric, one firm choosing \(f\) and the other \(i\). Although both firms have the same level of equity, they choose different technologies and incur different capital expenditures. A flexible firm may go bankrupt if demand is low when it is opposed to a flexible firm. It can eliminate this risk if it chooses the inflexible technology, allowing a reduction in debt and an increase in profit when demand is low at the cost of a reduction in profit when demand is high. The expected value and volatility of profit decrease. But once one firm has switched to \(i\), the other firm finds it better to stick to \(f\). Finally, if the common equity level is small, \(A < 0.85\), the equilibrium is again \((f, f)\), since firms go bankrupt in the bad state of demand whatever their technologies. In this example, firms may invest more in equilibrium if they face either no or severe financial hardship than if they face intermediate hardship.

When the equity levels are different, new cases appear (see Figure 1'). We consider only the cases where \(A_1 > A_2\), the cases for which firm 2 has more equity being symmetric.\(^{15}\) There are values for which there exist no equilibrium in pure strategies: one firm’s best reply is to mimic the technological choice of its rival while the other firm’s best reply is to choose a technology different from its rival’s. One should notice that the technological choice of a firm is not necessarily a monotonic function of its own equity level, given the equity level of its competitor: for example, if \(A_2\) is in the interval \((0, 0.85)\), the equilibria are such that firm 1 invests in the more costly flexible technology if its equity level is relatively small, in the less costly inflexible technology for higher equity levels, and again in the flexible technology if its equity level is large.\(^{16}\) One can also observe that the technological choice (and capital expenditures) of a firm may be a

\(^{15}\)The reader will have observed that Figure 1 illustrating the case \(A_1 = A_2\) is indeed the diagonal of Figure 1'.

\(^{16}\)Hence, the equilibrium investment level of a firm is a non-monotonic function of its level of financial hardship. The average leverage ratio of the firm is 0.88 in the first interval, 0.55 in the second and 0.26 in the third. The extent of leverage for non-financial corporations is of the order of 0.50 in G-7 countries, with Italy and France being on the high side at about 0.65, as measured by the average of the first two columns of Table III(B) of Rajan and Zingales (1995).
non-monotonic function of the equity level of its competitor, given its own equity level.

This example is very instructive. It shows that technological flexibility choices by firms depend on their level of equity financing or internal liquidity. Hence, in two similar industry contexts, technological choices may differ if the firms have different internal liquidity levels or different access to equity financing. They may also differ within an industry even if firms have the same level of equity, for example in example 1 if \( A_1 = A_2 \in (0.85, 4.37) \). One cannot predict which technological configuration will emerge simply from observing demand and costs conditions. Liquidity matters not only for the level of investment in the industry but also for the type of investment undertaken.

The following two examples illustrate among other things the changes in technological configurations when there is a decrease in the low level of demand (\( \alpha_1 \)) relative to the capacity of the inflexible technology (\( x \)).

**Example 2:** \( \alpha_1 = 5 \ (\omega \in \Omega_2) \)

**FIGURE 2**

Equilibrium technological configurations in example 2, \( \omega \in \Omega_2 \):

in \( Y \), \((f, f)\) and \((i, i)\).

If both firms have high equity levels (\( A \geq 7.69 \)), the industry equilibrium is \((f, f)\). As the common equity level decreases, the best reply to inflexibility becomes inflexibility and a second equilibrium appears, \((i, i)\). The firms may fall into a flexibility trap since \((i, i)\) would be more profitable for both of them. The existence of these two pure strategy equilibria may be explained by the strategic value of flexibility. Assume that the initial situation is \((i, i)\). If a firm changes its technology and chooses flexibility, it will be able to better adapt its output level to the demand level. It will decrease its production when the demand is low and increase it when the demand is high. This increases the firm’s profit but not enough to cover the larger investment cost of the flexible technology. But if the other firm is also flexible, then adopting the flexible technology has a strategic effect: the firm commits itself in a credible way to a higher output level when
demand is high. This commitment induces the other firm, also flexible, to decrease its output level when demand is high. In this context, flexibility has a positive strategic value for the firm. Moreover, when a firm adopts the flexible technology, the value of flexibility increases for the other firm as well. This effect explains the existence of two pure strategy equilibria. If equity decreases even more, below 5.94, the unique equilibrium is \((i, i)\). A flexible firm goes bankrupt when the demand is low whatever the technology of its rival is. Firms can avoid bankruptcy by adopting an inflexible technology. So inflexibility becomes a dominant strategy.\(^{18}\) Below 2.8, adopting inflexibility decreases the risk of bankruptcy (without eliminating it) only if the other firm is also inflexible and flexibility is again the best reply to flexibility: there are two technological equilibrium configuration, \((f, f)\) and \((i, i)\). Finally, for very low equity financing, the unique equilibrium is again \((f, f)\) as expected. If equity levels differ, other equilibria appear (see Figure 2').

In the next example, the capacity of the inflexible technology is so high relative to the low market size \((\omega \in \Omega_3)\) that a firm using this technology always shuts down when the demand is low. As a result, the probability of bankruptcy of an inflexible firm is strictly positive as soon as its debt is strictly positive (for \(A < 5.5\)).

**Example 3:** \(\alpha_1 = 3\) \((\omega \in \Omega_3)\)

The common equity level case is illustrated in Figure 3 and the more general case of asymmetric levels in Figure 3'.

**FIGURE 3**

Equilibrium technological configurations in example 3, \(\omega \in \Omega_3\):

\[
\text{[in } Z, (i, f) \text{ or } (f, i)]
\]

\[
\begin{align*}
0 & \quad 5.5 & \quad 6.54 & \quad 7.63 & \quad 8.5 & \quad A \\
(f, f) & \quad (i, i) & \quad Z & \quad (f, f)
\end{align*}
\]

\(^{17}\)This is reminiscent of Brander and Lewis (1986) result but for a different reason: it is the type of technology which matters here rather than simply the level of debt financing.

\(^{18}\)If equity is in the interval \((2.8, 5.5)\), the choice of an inflexible technology does not eliminate the risk of bankruptcy when the other firm is inflexible but reduces it from \(\mu\) to \(\mu/2\). The unique equilibrium remains \((i, i)\).
In this example the bankruptcy threshold of a flexible firm is quite high, so that for intermediate levels of equity, the firm’s best response switches from flexibility to inflexibility (to eliminate its probability of bankruptcy) for $5.5 < A < 7.63$ if the competitor is flexible, and for $5.5 < A < 6.54$ if the competitor is inflexible. If equity levels are low ($A < 5.5$), the positive effect of the inflexible technology on bankruptcy risk disappears and the firms end up in a $(f, f)$ equilibrium as when equity financing is large.

In each of the first three examples, the equilibrium technological configuration is always $(f, f)$ when equity is large. This is not a general result as the following example illustrates.

**Example 4:** ($\omega \in \Omega_3$)

$$\mu = 0.1, \alpha_1 = 4, \alpha_2 = 15, x = 5, \beta = 1, c = 0.2, K = 4, H = 0.5, B = 6.$$  

The common equity level case is illustrated in Figure 4 and the more general case of asymmetric levels in Figure 4′.

**FIGURE 4**

Equilibrium technological configurations in example 4, $\omega \in \Omega_3$

[in $Z$, $(i, f)$ or $(f, i)$]

In this example, the firms both choose the inflexible technology if they have a relatively large level of equity, $A > 4$. For intermediate equity levels, $2.9 < A < 4$, they both switch to the flexible technology. For lower equity levels, $0.89 < A < 2.9$, they choose different technologies and for even lower equity levels, $A < 0.89$, they both come back to the inflexible technology, as expected. The case of asymmetric equity positions is illustrated in Figure 4′. The capacity of the inflexible technology relative to the low level of demand is such that a firm using this technology always shuts down when the demand is low. As a result, the probability of bankruptcy of an inflexible firm is positive as soon as its debt is positive. A leveraged firm will then prefer to switch to a flexible technology, thereby eliminating the risk of bankruptcy. When the firm’s level of debt financing is larger, choosing a flexible technology eliminates the risk of bankruptcy if the other
firm is inflexible but not if the other firm is flexible. Therefore in the asymmetric equilibrium, one firm switches to the flexible technology to eliminate its risk of bankruptcy while the other keeps an inflexible technology and a positive probability of bankruptcy. If equity levels are very low, the real option value of flexibility disappears and the firms end up in a \((i, i)\) equilibrium as when equity is very large. However, if the firm is mainly an equity financed firm, as firm 1 in Figure 4' when \(A_1 > 4\), it may choose the inflexible technology to gain a commitment advantage on the product market. This explains the \((i, f)\) equilibrium when \(A_1 > 4\) and \(A_2 \in (0.89, 4)\): firm 1 has no debt but invest less than firm 2 whose leverage is on average equal to 0.57 and therefore is mainly financed through debt.

We can conclude this section 4 by stating that the impact of debt or equity financing on the technological configuration of an industry is a rather subtle non-monotonic one combining decision theoretic effects, real option effects and strategic effects. Hence the correlation between the leverage level and the investment level can in theory be positive or negative overall because the relationship between the two is non-monotonic.

5 The strategic value of equity

The fact that the level of equity financing, assumed to be exogenous till now, can change the technological best reply functions suggests that the level of equity could be chosen strategically. Note however that the best responses are functions of both the equity level and the bankruptcy cost which are substitute commitment factors. Hence it is the pair \((A_h, B)\) which generates a strategic value. In order to appreciate the competitive potential in an industry, we must look at what could be called the \textit{industry commitment index}, a function of both the level of equity financing and the bankruptcy cost.\(^\text{19}\)

5.1 Debt financing as a commitment device

We will assume in this section that the entrepreneur’s initial wealth is larger than \(K + H\) but that in a preliminary stage 0, the two entrepreneurs choose simultaneously the amounts \(A_h\) they will invest in their respective firms. If the invested capital is lower than the cost of the

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\(^{19}\text{Leach, Moyen and Yang (2003) develop a two factor model of deterrence where capacity and debt financing interact in determining the level of an intermediate good, which they call “output deterrence.”}\)
chosen technology, then the firm must borrow. We show next that there exist cases in which the entrepreneurs decide to finance their firms in part through debt in order to modify in a credible way their technological reaction functions.

Let us examine again Example 1 (Figure 1'). If the firms are whole equity firms, the technological equilibrium is \((f, f)\). Each firm’s expected profit is then equal to 5.74 (see Appendix C) even if in the technological configuration \((i, i)\) their common expected profit would be higher at 7.85 but \((i, i)\) is not an equilibrium configuration. When the firms are all equity financed, they play a prisoner dilemma game. If they decrease their equity capital, they alter the payoff matrix underlying their best reply functions and they avoid the dilemma. In Example 1, if both firms have an equity capital of \(A \in (5.2, 6.1)\), they play a subgame admitting \((f, f)\) and \((i, i)\) as equilibria and they never go bankrupt. By reducing their equity capital, the firms credibly commit not to reply to inflexibility by flexibility. When the rival is inflexible, a flexible firm earns a high profit level when demand is high but a low profit level when demand is low. Hence, if the firm must borrow a large amount to invest in the flexible technology, it goes bankrupt when demand is low. The expected bankruptcy cost \((\mu B = 3)\) makes flexibility less attractive than inflexibility when the other firm is inflexible. When the best reply to inflexibility switches from flexibility to inflexibility, the firms avoid the prisoner dilemma and play a coordination game. Therefore firms can both increase their expected profits by choosing strategically their capital structure: debt has strategic value.

In Example 2 (Figure 2'), the firms, by reducing equity to \(A_h \in (5.94, 7.69)\), modify their best reply to inflexibility and the technological configuration \((i, i)\) which is more profitable for the two firms becomes an equilibrium. The firms would be better off eliminating the configuration \((f, f)\) as an equilibrium by reducing even more their equity capital to \(A_h \in (2.8, 5.94)\) but such capital structures are not equilibria of the preliminary stage game: one firm would be better off deviating and increasing its equity capital to \(A_h > 7.69\) to induce the configuration \((f, i)\) as the unique equilibrium. The profit of the higher equity financed firm would be greater but the profit of its competitor would be lower. This problem can be avoided if firms can choose their capital structure sequentially, a form of coordination among firms. In this case the leader chooses \(A_1 \in (5.94, 7.69)\) and the follower chooses \(A_2 \in (2.8, 5.94)\). The unique equilibrium is then \((i, i)\). In this configuration, the firms never go bankrupt. So raising debt financing involve
no risk of bankruptcy.

5.2 The strategic increase of bankruptcy costs

We showed above that the capital structure can be used strategically in order to influence the technological choice of the rival when the bankruptcy costs are high enough to change the technological best reply functions. A reduction in bankruptcy costs would no more allow this strategic use of the capital structure and therefore may indeed decrease the expected profits of the firms. In these cases, the firms could try to artificially increase the bankruptcy costs. A simple way to do that is, for entrepreneurs, to offer judiciously chosen assets as collateral for their debt or to induce banks to ask for those collateral assets. Another way to increase the bankruptcy costs is to delegate the investment decision to a manager to be fired in case of bankruptcy. If the control of the firm gives to the manager enough private benefits (perks), then the manager will choose the technology which minimize the firm’s bankruptcy probability. In order to increase the bankruptcy costs and give them strategic value, shareholders can provide more private benefits to the manager.

The bank and the entrepreneur may have different evaluations of the collateral assets, some assets having a greater value for the debtor than for the creditor. In general, this difference is inefficient and the contracting parties have an interest to choose the assets with the lowest evaluation differential. However Williamson (1983) argues that it may be better in some contracts to choose collateral assets which have a low value for the creditor. This can prevent a cancellation of the contract aimed at seizing the collateral assets. Our analysis proposes an additional explanation for this kind of behavior: increasing the collateral assets evaluation differential increases the bankruptcy cost for the borrower and so increases the commitment power of debt.21

20See Freixas and Rochet (1997, chapters 4 and 5) for references.
21We find in Shakespeare, The merchant of Venice [I, 3], an extreme example of the this type of debt contract:

"Shylock: This kindness will I show.
Go with me to a notary, seal me there
Your single bond, and, in a merry sport,
If you repay me not on such a day,
In such a place, such a sum or sums as are
Expressed in the condition, let the forfeit
Be nominated for an equal pound
Of your fair flesh, to be cut off and taken
In what part of your body pleaseth me.
Antonio: Content, in faith - I'll seal to such a bond,"
Bankruptcy costs and equity financing levels have significant impacts on the equilibrium technological configurations in an industry. These effects arise because leveraged firms, either flexible or inflexible, may want to change their plans regarding technology adoption in order to reduce their probability of bankruptcy. We have shown through illustrative examples based on a bare-bone tractable model that the effect of equity financing (or internal liquidity) is non-monotonic. An industry may very well have the same technology equilibrium for low and high leverage levels, with a different technology equilibrium for intermediate leverage levels. We have also illustrated the role played by the inflexible technology capacity level and the size of the market under low demand.

The main determinants of capital structure, as modeled and identified so far in the economics and finance literature, can be regrouped under four major headings: taxation, information asymmetries with non congruence of interests, competitive positioning, and finally corporate control.22 We showed that the endogeneity of technological choices is likely to be an important determinant of both the optimal capital structure and the relationship between capital structure and product market competition.

Recall that according to Brander and Lewis (1986), a firm’s output level increases with its debt level whereas in Glazer (1994), the output level decreases in the first period and increases in the second period as debt increases, and in Showalter (1995), higher debt induces lower prices, that is higher output levels, when costs are uncertain, while the opposite effect holds when demand is uncertain. Leach, Moyen and Yang (2003) consider a leader-follower framework where the leader chooses its capacity and debt financing levels in stage 1 while in stage 2 the follower chooses its capacity, debt financing and production levels simultaneously with the leader choosing its production level. Both capacity investment and debt financing are used as deterrence factors by the leader-incumbent. They show that lower levels of debt financing can achieve the Brander-Lewis effect on the competitor. They empirically test the deterrent role of capacity and debt financing by looking at the telecommunications industry in the U.S. where competition was And say there is much kindness in the Jew.”

significantly favored after 1996. Their empirical findings support the hypothesis that significant post-1996 advantage was obtained or captured by those incumbents who increased significantly their leverage ratio. Similarly in our model, the link between debt levels and output levels is somewhat more subtle than the previous literature suggested since debt not only induces changes in output and prices given the technologies but also changes in the technologies or production cost functions themselves. We showed that leveraged firms may under some conditions invest in inflexible technologies resulting in less volatility in industry output but more volatility in prices, while under other conditions they would invest in flexible technologies resulting in more volatility in industry output but less volatility in prices. Therefore, the effects characterized by Brander and Lewis (1986), Glazer (1994) and Showalter (1995) among others, depend closely on the implicit assumption that a single technology is available. If firms are allowed to choose between different technologies – we looked in this paper at technologies with different ability to adjust to changing market conditions –, the impacts of debt financing becomes in general non-monotonic.

The relationship between a firm’s level of capital expenditures and level of internal liquidity is a central question in modern finance. Recent empirical regularities obtained by Kaplan and Zingales (1997) and Cleary (1999) showing that investments by the less financially constrained firms are significantly more sensitive to internal liquidity than the investments of the more financially constrained firms, have disrupted the earlier consensus, reviewed in Hubbard (1998), to the effect that investments by financially constrained firms were more sensitive to the level of internal free cash flows or liquidity than investments by high creditworthy firms. Cleary (1999) states that “Investment decisions of firms with high creditworthiness (according to traditional financial ratios) are extremely sensitive to the availability of internal funds; less creditworthy firms are much less sensitive to internal fund availability.” The theoretical underpinning of the conflicting evidence remains a subject of debate and research. Our analysis emphasizes the strategic effects of capital structure through not only quantity and price changes at the production stage but also through changes at the technology adoption and investment stage. It complements the analysis of Fazzari, Hubbard and Petersen (1988, 2000), Kaplan and Zingales (1997, 2000) and Cleary (1999). Those authors studied the impact of capital structure on the level of investment in firms but not on the type of investment or technologies acquired through
these investments. Clearly, the type of technology chosen is likely to have far reaching impacts on the organizational structure and the market strategy of the firm. For some market contexts or industry parameters, debt has strategic value and increases a firm’s expected profit but in other contexts debt is a source of weakness for the firm and decreases expected profit. Debt may sometimes help solving the coordination problem due to multiple equilibrium technological configurations but may also lead to the selection of a Pareto-dominated equilibrium.

The non-monotonicity of the relationship between the firm’s equity financing level, which in our simplified model represents the level of internal liquidity or the creditworthiness of the firm, and its level of investment in different types of technologies, in particular the fact that this relationship may be \( \cap \)-shaped or \( \cup \)-shaped, suggests that in aggregating data over a large number of firms, one may find in theory more or less sensitivity of investments to the firm’s internal liquidity as the level of financial hardship varies. Hence, if enough firms find themselves in a \( \cup \)-shaped relationship, that is more creditworthy types invest more than financially constrained types because the latter find desirable to trade market opportunities for a lower probability of bankruptcy, one may very well predict the empirical results of Kaplan and Zingales (1997) and Cleary (1999). On the other hand, if enough firms find themselves in a \( \cap \)-shaped relationship, that is more creditworthy types invest less than financially constrained types because the latter find desirable to forego profit opportunities in order to reduce their probability of financial distress, one may very well predict the ‘consensus’ empirical results surveyed by Hubbard (1998).

We like to think that our results are a step in trying to explain those conflicting empirical regularities. We like to think also that our results contribute to a better understanding of the complex interconnections between capital structure, technological flexibility, and strategic market behavior not only in the presence of strategic value maximization but also in the context of value maximizing corporate risk management.

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23 This determinant is likely to be even more important than the other ones in part because other less costly means may be available to achieve the objectives behind the other determinants. For instance, conflicts between stakeholders can be softened by more sophisticated managerial contracts and the likelihood of a hostile takeover can be reduced by a strategic allocation of voting rights.

24 We clearly have also a non-monotonic relationship at the industry level.

25 See also the subsequent discussions in Fazzari, Hubbard and Petersen (2000) and Kaplan and Zingales (2000).
APPENDIX

A Second stage equilibria and first stage expected profits

By assumption, the state of demand is observed before the second stage Cournot competition takes place. For a state of the market $\alpha$, the Cournot reaction function of a flexible firm $h$ is

$$q_h = \frac{1}{2}((\alpha - c)/\beta - q_j), \ j \neq h.$$  

For $\omega \in \Omega_1$, both firms are always better off producing than not and we get:

- if both firms are flexible, the production level of each firm is $(\alpha_k - c)/3\beta$ and $\pi_k(f, f, \Omega_1) = (\alpha_k - c)^2/9\beta$; the expected profit of each firm is given by (3) with
  $$\hat{E}\Pi(f, f, \Omega_1) = \frac{1}{9\beta} \left[ \mu (\alpha_1 - c)^2 + (1 - \mu) (\alpha_2 - c)^2 \right] - (K + H),$$

- if one firm is flexible and the other is inflexible, the production level of the flexible [inflexible] firm is $\frac{1}{2}((\alpha_k - c)/\beta - x)$ [x]; we have $\pi_k(f, i, \Omega_1) = (\alpha_k - c - \beta x)^2/4\beta$ and $\pi_k(i, f, \Omega_1) = \frac{1}{2}(\alpha_k - c - \beta x) x$; the expected profit of the flexible [inflexible] firm is given by (3) [(6)] with
  $$\hat{E}\Pi(f, i, \Omega_1) = \frac{1}{4\beta} \left[ \mu (\alpha_1 - c - \beta x)^2 + (1 - \mu) (\alpha_2 - c - \beta x)^2 \right] - (K + H),$$
  $$\hat{E}\Pi(i, f, \Omega_1) = \frac{1}{2} [\mu \alpha_1 + (1 - \mu) \alpha_2 - c - 2\beta x] x - K,$$

- if both firms are inflexible, the production level of each firm is $x$; we have $\pi_k(i, i, \Omega_1) = (\alpha_k - c - 2\beta x) x$; the expected profit of each firm is given by (6) with
  $$\hat{E}\Pi(i, i, \Omega_1) = [\mu \alpha_1 + (1 - \mu) \alpha_2 - c - 2\beta x] x - K.$$  

For $\omega \in \Omega_2$, we get:

- for $(f, f)$ and $(f, i)$, the equilibria are the same as in the case $\omega \in \Omega_1$ above

- for $(i, i)$, if demand is low, one firm shuts down and the other enjoys a monopoly position, that is $\pi_k(i, i, \Omega_2) = (\alpha_k - c - \beta x) x$; the expected profit of both firms is given by (9) with
  $$\hat{E}\Pi(i, i, \Omega_2) = \mu \frac{1}{2} (\alpha_1 - c - \beta x) x + (1 - \mu) (\alpha_2 - c - 2\beta x) x - K.$$  

For $\omega \in \Omega_3$, we get:
- for \((f, f)\), the equilibrium is the same as in the case where \(\omega \in \Omega_1\)

- for \((f, i)\), the inflexible firm shuts down when demand is low whereas the flexible firm enjoys a monopoly position, that is \(\pi_k(f, i, \Omega_3) = (\alpha_k - c)^2/4\beta\); the expected profit of the firms are given by (3) and (6) with

\[
\bar{E}\Pi(f, i, \Omega_3) = \frac{1}{4\beta} \left[ \mu (\alpha_1 - c)^2 + (1 - \mu) (\alpha_2 - c - \beta x)^2 \right] - (K + H),
\]

\[
\bar{E}\Pi(i, f, \Omega_3) = \frac{1}{2} (1 - \mu) (\alpha_2 - c - \beta x) x - K
\]

- for \((i, i)\), both firms shut down when demand is low and the expected profit of each firm is given by (6) with

\[
\bar{E}\Pi(i, i, \Omega_3) = (1 - \mu) (\alpha_2 - c - 2\beta x) x - K.
\]

## B Best response in technology

### Best reply to in flexibility

Let \(A(i, i, \Omega)\) and \(A(f, i, \Omega)\) be the minimum equity required for not going bankrupt in the low state of demand when choosing respectively the inflexible and the flexible technology. Those minimum levels of equity are positive by assumption, that is \(\pi_1(t, t', \Omega)\) is less than \(K\) or \(K + H\) for all \(t, t'\) and \(\Omega\). \(^{26}\) This assumption is made only to simplify the presentation of the different cases, without any loss of generality.

\[
A(i, i, \Omega) = K - \pi_1(i, i, \Omega) > 0
\]

\[
A(f, i, \Omega) = K + H - \pi_1(f, i, \Omega) > 0
\]

and so, \(0 < A(i, i, \Omega) < A(f, i, \Omega)\) iff \(H > \pi_1(f, i, \Omega) - \pi_1(i, i, \Omega)\).

### Best reply to in flexibility for \(\omega \in \Omega_1 \cup \Omega_3\)

From Appendix A, we have in this case: \(A(i, i, \Omega_1) = K - (\alpha_1 - c - 2\beta x)x\), \(A(f, i, \Omega_1) = K + H - (\alpha_1 - c - \beta x)^2/4\beta\), \(A(i, i, \Omega_3) = K\), \(A(f, i, \Omega_3) = K + H - (\alpha_1 - c)^2/4\beta\). Inflexibility is the best response to in flexibility:

\(^{26}\)More precisely, \(K > (\alpha_1 - c - \beta x)x\) and \(K + H > \max\{(\alpha_1 - c)^2/9\beta, (\alpha_1 - c - \beta x)^2/4\beta\}\).
• when $H > \pi_1(f, i, \Omega) - \pi_1(i, i, \Omega)$, that is $A(i, i, \Omega) < A(f, i, \Omega)$, iff:

$$
\bar{E}\Pi(i, i, \Omega) - \mu B \geq \bar{E}\Pi(f, i, \Omega) - \mu B, \quad \text{for } A_h < A(i, i, \Omega)
$$

$$
\bar{E}\Pi(i, i, \Omega) \geq \bar{E}\Pi(f, i, \Omega) - \mu B, \quad \text{for } A(i, i, \Omega) < A_h < A(f, i, \Omega) \quad (12)
$$

$$
\bar{E}\Pi(i, i, \Omega) \geq \bar{E}\Pi(f, i, \Omega), \quad \text{for } A(f, i, \Omega) < A_h
$$

• when $H < \pi_1(f, i, \Omega) - \pi_1(i, i, \Omega)$, that is $A(f, i, \Omega) < A(i, i, \Omega)$, iff:

$$
\bar{E}\Pi(i, i, \Omega) - \mu B \geq \bar{E}\Pi(f, i, \Omega) - \mu B, \quad \text{for } A_h < A(f, i, \Omega)
$$

$$
\bar{E}\Pi(i, i, \Omega) - \mu B \geq \bar{E}\Pi(f, i, \Omega), \quad \text{for } A(f, i, \Omega) < A_h < A(i, i, \Omega) \quad (13)
$$

$$
\bar{E}\Pi(i, i, \Omega) \geq \bar{E}\Pi(f, i, \Omega), \quad \text{for } A(i, i, \Omega) < A_h.
$$

Best reply to inflexibility for $\omega \in \Omega_2$

From Appendix A, we have in this case: $A(i, i, \Omega_2) = K - (\alpha_1 - c - \beta x)x$ if the firm operates, $A(f, i, \Omega_2) = K + H - (\alpha_1 - c - \beta x)^2/4\beta$. Inflexibility is the best reply to inflexibility

• when $H > \pi_1(f, i, \Omega_2)$, that is $A(i, i, \Omega_2) < K < A(f, i, \Omega_2)$, iff:

$$
\bar{E}\Pi(i, i, \Omega_2) - \mu B > \bar{E}\Pi(f, i, \Omega_2) - \mu B, \quad \text{for } A_h < A(i, i, \Omega_2)
$$

$$
\bar{E}\Pi(i, i, \Omega_2) - \frac{1}{2}\mu B > \bar{E}\Pi(f, i, \Omega_2) - \mu B, \quad \text{for } A(i, i, \Omega_2) < A_h < K \quad (14)
$$

$$
\bar{E}\Pi(i, i, \Omega_2) > \bar{E}\Pi(f, i, \Omega_2) - \mu B, \quad \text{for } K < A_h < A(f, i, \Omega_2)
$$

$$
\bar{E}\Pi(i, i, \Omega_2) > \bar{E}\Pi(f, i, \Omega_2), \quad \text{for } A(f, i, \Omega_2) < A_h
$$

• when $\pi_1(i, i, \Omega_2) < H < \pi_1(f, i, \Omega_2)$, that is $A(i, i, \Omega_2) < A(f, i, \Omega_2) < K$, iff

$$
\bar{E}\Pi(i, i, \Omega_2) - \mu B > \bar{E}\Pi(f, i, \Omega_2) - \mu B, \quad \text{for } A_h < A(i, i, \Omega_2)
$$

$$
\bar{E}\Pi(i, i, \Omega_2) - \frac{1}{2}\mu B > \bar{E}\Pi(f, i, \Omega_2) - \mu B, \quad \text{for } A(i, i, \Omega_2) < A_h < A(f, i, \Omega_2)
$$

$$
\bar{E}\Pi(i, i, \Omega_2) - \frac{1}{2}\mu B > \bar{E}\Pi(f, i, \Omega_2), \quad \text{for } A(f, i, \Omega_2) < A_h < K \quad (15)
$$

$$
\bar{E}\Pi(i, i, \Omega_2) > \bar{E}\Pi(f, i, \Omega_2), \quad \text{for } K < A_h
$$
• When $H < \pi_1(i,i,\Omega_2)$, that is $A(f, i, \Omega_2) < A(i, i, \Omega_2) < K$, iff

\[
\begin{align*}
\widehat{E}\Pi(i, i, \Omega_2) - \mu B &> \widehat{E}\Pi(f, i, \Omega_2) - \mu B, \quad \text{for } A_h < A(f, i, \Omega_2) \\
\widehat{E}\Pi(i, i, \Omega_2) - \mu B &> \widehat{E}\Pi(f, i, \Omega_2), \quad \text{for } A(f, i, \Omega_2) < A_h < A(i, i, \Omega_2) \\
\widehat{E}\Pi(i, i, \Omega_2) - \frac{1}{2} \mu B &> \widehat{E}\Pi(f, i, \Omega_2), \quad \text{for } A(i, i, \Omega_2) < A_h < K \\
\widehat{E}\Pi(i, i, \Omega_2) &> \widehat{E}\Pi(f, i, \Omega_2), \quad \text{for } K < A_h
\end{align*}
\]

(16)

Best reply to flexibility

If the competitor firm adopted the flexible technology, we now have

\[
\begin{align*}
A(i, f, \Omega) &= K - \pi_1(i, f, \Omega) > 0 \\
A(f, f, \Omega) &= K + H - \pi_1(f, f, \Omega) > 0
\end{align*}
\]

(17)

and so, $0 < A(i, f, \Omega) < A(f, f, \Omega)$ iff $H > \pi_1(f, f, \Omega) - \pi_1(i, f, \Omega)$.

Best reply to flexibility for $\omega \in \Omega_1 \cup \Omega_2 \cup \Omega_3$.

From Appendix A, we have in this case: $A(i, f, \Omega_1) = A(i, f, \Omega_2) = K - \frac{1}{2}(\alpha_1 - c - \beta x)x$, $A(f, f, \Omega_1) = A(f, f, \Omega_2) = A(f, f, \Omega_3) = K + H - (\alpha_1 - c)\frac{2}{9}\beta$, $A(i, f, \Omega_3) = K$. Inflexibility is the best response to flexibility:

• when $H > \pi_1(f, f, \Omega) - \pi_1(i, f, \Omega)$, that is $A(i, f, \Omega) < A(f, f, \Omega)$, iff:

\[
\begin{align*}
\widehat{E}\Pi(i, f, \Omega) - \mu B &\geq \widehat{E}\Pi(f, f, \Omega) - \mu B, \quad \text{for } A_h < A(i, f, \Omega) \\
\widehat{E}\Pi(i, f, \Omega) &\geq \widehat{E}\Pi(f, f, \Omega) - \mu B, \quad \text{for } A(i, f, \Omega) < A_h < A(f, f, \Omega) \\
\widehat{E}\Pi(i, f, \Omega) &\geq \widehat{E}\Pi(f, f, \Omega), \quad \text{for } A(f, f, \Omega) < A_h
\end{align*}
\]

(18)

• when $H < \pi_1(f, f, \Omega) - \pi_1(i, f, \Omega)$, that is $A(f, f, \Omega) < A(i, f, \Omega)$, iff:

\[
\begin{align*}
\widehat{E}\Pi(i, f, \Omega) - \mu B &\geq \widehat{E}\Pi(f, f, \Omega) - \mu B, \quad \text{for } A_h < A(f, f, \Omega) \\
\widehat{E}\Pi(i, f, \Omega) - \mu B &\geq \widehat{E}\Pi(f, f, \Omega), \quad \text{for } A(f, f, \Omega) < A_h < A(i, f, \Omega) \\
\widehat{E}\Pi(i, f, \Omega) &\geq \widehat{E}\Pi(f, f, \Omega), \quad \text{for } A(i, f, \Omega) < A_h
\end{align*}
\]

(19)
C Examples used in the text

Example 1 \((\Omega_1)\): \(\alpha_1 = 6.3; \alpha_2 = 15, \mu = 0.5, x = 3, \beta = 1, c = 0.2, K = 5.5, H = 3, B = 6.\)

Bankruptcy thresholds:

\[
\begin{align*}
A(f, f, \Omega_1) &= 4.37, \quad A(i, f, \Omega_1) = 0.85 \\
A(f, i, \Omega_1) &= 6.10, \quad A(i, i, \Omega_1) = 5.20
\end{align*}
\]

Profits when demand is low:

\[
\begin{align*}
\pi_1(f, f, \Omega_1) &= 4.13, \quad \pi_1(i, f, \Omega_1) = 4.65 \\
\pi_1(f, i, \Omega_1) &= 2.40, \quad \pi_1(i, i, \Omega_1) = 0.30
\end{align*}
\]

Profit levels:

\[
\begin{align*}
6.1 \leq A_h & \quad E\Pi (f, f) = 5.74 > E\Pi (i, f) = 5.68 \\
& \quad E\Pi (f, i) = 10.11 > E\Pi (i, i) = 7.85
\end{align*}
\]

\[
\begin{align*}
5.2 \leq A_h < 6.1 & \quad E\Pi (f, f) = 5.74 > E\Pi (i, f) = 5.68 \\
& \quad E\Pi (f, i) = 7.11 < E\Pi (i, i) = 7.85
\end{align*}
\]

\[
\begin{align*}
4.37 \leq A_h < 5.2 & \quad E\Pi (f, f) = 5.74 > E\Pi (i, f) = 5.68 \\
& \quad E\Pi (f, i) = 7.11 > E\Pi (i, i) = 7.85
\end{align*}
\]

\[
\begin{align*}
0.85 < A_h < 4.37 & \quad E\Pi (f, f) = 2.74 < E\Pi (i, f) = 5.68 \\
& \quad E\Pi (f, i) = 7.11 > E\Pi (i, i) = 4.85
\end{align*}
\]

\[
\begin{align*}
A_h < 0.85 & \quad E\Pi (f, f) = 2.74 > E\Pi (i, f) = 2.68 \\
& \quad E\Pi (f, i) = 7.11 > E\Pi (i, i) = 4.85
\end{align*}
\]
Example 2 ($\Omega_2$): $\alpha_1 = 5; \alpha_2 = 15, \mu = 0.5, x = 3, \beta = 1, c = 0.2, K = 5.5, H = 3, B = 6.$

Bankruptcy thresholds:

\[
\begin{align*}
A(f, f, \Omega_2) &= 5.94, & A(i, f, \Omega_2) &= 2.80 \\
A(f, i, \Omega_2) &= 7.69, & A(i, i, \Omega_2) &= 5.50 \text{ and } 0
\end{align*}
\]

Profits when demand is low:

\[
\begin{align*}
\pi_1(f, f, \Omega_2) &= 2.56, & \pi_1(i, f, \Omega_2) &= 2.70 \\
\pi_1(f, i, \Omega_2) &= 0.81, & \pi_1(i, i, \Omega_2) &= \begin{cases} 
0 \text{ with probability } 1/2 \\
5.4 \text{ with probability } 1/2 
\end{cases}
\end{align*}
\]

Profit levels:

\[
\begin{align*}
7.69 \leq A_h & \quad \mathbb{E} \pi(f, f) = 4.95 > \mathbb{E} \pi(i, f) = 4.7 \\
& \quad \mathbb{E} \pi(f, i) = 9.31 > \mathbb{E} \pi(i, i) = 9.05 \\
5.94 \leq A_h < 7.69 & \quad \mathbb{E} \pi(f, f) = 4.95 > \mathbb{E} \pi(i, f) = 4.7 \\
& \quad \mathbb{E} \pi(f, i) = 6.31 < \mathbb{E} \pi(i, i) = 9.05 \\
5.5 \leq A_h < 5.94 & \quad \mathbb{E} \pi(f, f) = 1.95 < \mathbb{E} \pi(i, f) = 4.7 \\
& \quad \mathbb{E} \pi(f, i) = 6.31 < \mathbb{E} \pi(i, i) = 9.05 \\
2.8 \leq A_h < 5.5 & \quad \mathbb{E} \pi(f, f) = 1.95 < \mathbb{E} \pi(i, f) = 4.7 \\
& \quad \mathbb{E} \pi(f, i) = 6.31 < \mathbb{E} \pi(i, i) = 7.55 \\
0.1 \leq A_h < 2.8 & \quad \mathbb{E} \pi(f, f) = 1.95 > \mathbb{E} \pi(i, f) = 1.7 \\
& \quad \mathbb{E} \pi(f, i) = 6.31 < \mathbb{E} \pi(i, i) = 7.55 \\
A_h < 0.1 & \quad \mathbb{E} \pi(f, f) = 1.95 > \mathbb{E} \pi(i, f) = 1.7 \\
& \quad \mathbb{E} \pi(f, i) = 6.31 > \mathbb{E} \pi(i, i) = 6.05
\end{align*}
\]
Example 3 ($\Omega_3$): $\alpha_1 = 3$, $\alpha_2 = 15$, $\mu = 0.5$, $x = 3$, $\beta = 1$, $c = 0.2$, $K = 5.5$, $H = 3$, $B = 6$.

Bankruptcy thresholds:

\[
A(f, f, \Omega_3) = 7.63, \quad A(i, f, \Omega_3) = 5.50 \\
A(f, i, \Omega_3) = 6.54, \quad A(i, i, \Omega_3) = 5.50
\]

Profits when demand is low:

\[
\pi_1(f, f, \Omega_3) = 0.87, \quad \pi_1(i, f, \Omega_3) = 0 \\
\pi_1(f, i, \Omega_3) = 1.96, \quad \pi_1(i, i, \Omega_3) = 0
\]

Profit levels:

\[
\begin{align*}
7.63 \leq A_h & \quad \mathbb{E}\Pi(f, f) = 4.1 > \mathbb{E}\Pi(i, f) = 3.35 \\
& \quad \mathbb{E}\Pi(f, i) = 9.89 > \mathbb{E}\Pi(i, i) = 7.7 \\
6.54 \leq A_h < 7.63 & \quad \mathbb{E}\Pi(f, f) = 1.1 < \mathbb{E}\Pi(i, f) = 3.35 \\
& \quad \mathbb{E}\Pi(f, i) = 9.89 > \mathbb{E}\Pi(i, i) = 7.7 \\
5.5 \leq A_h < 6.54 & \quad \mathbb{E}\Pi(f, f) = 1.1 < \mathbb{E}\Pi(i, f) = 3.35 \\
& \quad \mathbb{E}\Pi(f, i) = 6.89 < \mathbb{E}\Pi(i, i) = 7.7 \\
A_h < 5.5 & \quad \mathbb{E}\Pi(f, f) = 1.1 > \mathbb{E}\Pi(i, f) = 0.35 \\
& \quad \mathbb{E}\Pi(f, i) = 6.89 > \mathbb{E}\Pi(i, i) = 4.7
\end{align*}
\]
Example 4 ($\Omega_3$): $\alpha_1 = 4$, $\alpha_2 = 15$, $\mu = 0.1$, $x = 5$, $\beta = 1$, $c = 0.2$, $K = 4$, $H = 0.5$, $B = 6$.

Bankruptcy thresholds:

$$A(f, f, \Omega_3) = 2.90, \quad A(i, f, \Omega_3) = 4.00$$
$$A(f, i, \Omega_3) = 0.89, \quad A(i, i, \Omega_3) = 4.00$$

Profits when demand is low:

$$\pi_1(f, f, \Omega_3) = 1.60, \quad \pi_1(i, f, \Omega_3) = 0$$
$$\pi_1(f, i, \Omega_3) = 3.61, \quad \pi_1(i, i, \Omega_3) = 0$$

Profit levels:

\[
\begin{align*}
4 \leq A_h & \quad E\Pi(f, f) = 17.56 < E\Pi(i, f) = 18.05 \\
& \quad E\Pi(f, i) = 17.47 < E\Pi(i, i) = 17.60 \\
2.9 \leq A_h < 4 & \quad E\Pi(f, f) = 17.56 > E\Pi(i, f) = 17.45 \\
& \quad E\Pi(f, i) = 17.47 > E\Pi(i, i) = 17.00 \\
0.89 \leq A_h < 2.9 & \quad E\Pi(f, f) = 16.96 < E\Pi(i, f) = 17.45 \\
& \quad E\Pi(f, i) = 17.47 > E\Pi(i, i) = 17.00 \\
A_h < 0.89 & \quad E\Pi(f, f) = 16.96 < E\Pi(i, f) = 17.45 \\
& \quad E\Pi(f, i) = 16.87 < E\Pi(i, i) = 17.00
\end{align*}
\]
References


Equilibrium technological configurations in example 1, $\omega \in \Omega_1$:

- in $Y$, $(f, f)$ and $(i, i)$;
- in $Z$, $(f, i)$ or $(i, f)$;
- in $W$, no equilibrium in pure strategies.
FIGURE 2′

Equilibrium technological configurations in example 2, $\omega \in \Omega_2$: in $Y$, $(f,f)$ and $(i,i)$. 

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure2p}
\caption{Equilibrium technological configurations in example 2, $\omega \in \Omega_2$: in $Y$, $(f,f)$ and $(i,i)$.
}
\end{figure}
Equilibrium technological configurations in example 3, \( \omega \in \Omega_3 \):

in \( Z \), \((f, i)\) or \((i, f)\).
FIGURE 4'
Equilibrium technological configurations in example 4, $\omega \in \Omega_3$:

in $\mathbb{Z}$, $(f, i)$ or $(i, f)$. 

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