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On the Relationship Between Financial Status and Investment in Technological Flexibility*

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Résumé / Abstract

Nous étudions les interactions entre le financement par actions et les choix de flexibilité technologique des entreprises menacées de faillites coûteuses. Nous montrons que le niveau de crise financière traversée par l'entreprise est un déterminant important dans le choix du niveau et du type d'investissement qu'elle va faire, soit une technologie inflexible moins coûteuse, soit une technologie flexible plus coûteuse. Nous montrons que le niveau de difficulté financière a un effet non monotone : au fur et à mesure que le niveau de financement par actions augmente, le choix technologique peut se modifier et le niveau d'investissement peut tout d'abord augmenter pour diminuer ensuite, ou vice versa, dépendant du différentiel du coût d'investissement, du coût de faillite, et selon que la technologie plus ou moins coûteuse est ou non la meilleure solution pour une entreprise sans dette. Le niveau de financement extérieur (endettement) peut être utilisé stratégiquement comme moyen de collusion non coopérative pour accroître les profits attendus des deux entreprises. Une entreprise peut également utiliser l'endettement comme un outil d'engagement pour accroître son propre profit attendu.

We study the interactions between equity financing and strategic technological flexibility choices of firms facing a threat of costly bankruptcy. We show that a firm's level of 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 expansive 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 (no debt) firm. The level of external financing (debt) may be used strategically as a non-cooperative collusion way to increase the expected profits of both firms. A firm may also use debt as a commitment device to increase its own expected profit.

Mots-clés : Financement interne, Endettement, Flexibilité technologique, Comportement stratégique
Keywords : Internal financing, Debt, Technological flexibility, Strategic behavior
J.E.L. Classificatio: L13, G32, D24

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1 Introduction

The relationship between a firm's level of investment 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.

The present paper deals primarily with the *type* of investment or technology chosen by firms which is related to the *level* of investment through the differential cost of alternative technologies. More specifically, we consider two main types of technologies, the dedicated but inflexible technologies and the flexible ones, the latter being more expensive in terms of investment outlays. Our paper is therefore related to the choice of technological flexibility by firms.

According to many business gurus and commentators, flexibility has become the Holy Grail in the 'new' economy where developments in globalization, information technologies and flexible manufacturing systems (FMS) have made the markets significantly more volatile. The increased 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 designing more powerful incentive systems and corporate governance rules to ensure better congruence of interests throughout the firm. Business International (1991) claims that the search for flexibility is the all-inclusive concept allowing an integrated understanding of most if not all recent developments in management theory. It claims also that increasing a firm's flexibility requires a concerted effort on many levels: introducing flatter organizational structures, investing in automated manufacturing, creating strong but malleable alliances, introducing incentive systems centered on results, etc. In economic theory terms, this means harnessing and exploiting the supermodularity features of the set of strategies.

We consider here a context of oligopolistic competition under uncertainty to study the relationships between financial structure or liquidity and technological flexibility investments. As we will see, flexibility has both positive and negative features and therefore the choice of its level in a corporation raises more subtle strategic issues than suggested in the gurus' writing and in the management literature in general. In terms of investment level, a flexible manufacturing system capable of producing a wider scope of products will typically be more expensive than a dedicated manufacturing system, not only in terms of the investment cost per se but also in terms of its impact on the internal organization of the firm and on its relations with suppliers and customers.[1] The evaluation of the proper flexibility spectrum in a firm, whether this flexibility comes from technological, organizational or contractual characteristics and decisions, requires an evaluation of the fine 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 features related to 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 market demand. Since the type of technology together with the cash flows generated will determine the probability of bankruptcy, we must consider that the financial and technological choices of a firm are simultaneously determined and interdependent. In turn, this implies that debt may be used strategically. Brander and Lewis (1986) show that the debt level may have a significant impact in an oligopolistic market under demand uncertainty as debt and limited liability induces firms to take more risky positions.[2] By increasing its debt level, a firm can at the second stage of the game decrease the equilibrium production level of its rival while increasing its own production level and therefore debt has a strategic value. With bankruptcy

[1] See Gerwin (1982, 1993), Mensah and Miranti (1989), Milgrom and Roberts (1990) and Boyer and Moreaux (1997) for convincing examples.

[2] As in Jensen and Meckling (1976).

costs (Brander and Lewis 1988), the link between debt and production becomes ambiguous: in some contexts, debt improves the competitive position of the firm but in others, debt is a source of weakness.[3]

All those industrial economics articles assume a given technology, more precisely a given production cost function. But as emphasized by Stigler (1939), firms have some degrees of freedom in choosing their cost functions. In this spirit, Lecostey (1994) and Boyer and Moreaux (1997) show that a way to commit to a production strategy is to choose a relatively inflexible technology.[4] The profitability trade-off in this case stems from the fact that a firm choosing an 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 show that a firm's level of financial hardship, measured by the level of debt financing, is an important determinant of the level and type of investment it chooses to make. When, facing an inflexible competitor, an all equity firm is better off choosing an inflexible [flexible] technology, then this choice remains the best option as the firm's level of equity financing decreases if either the differential investment cost between flexible and inflexible technologies is large [small] or the bankruptcy cost is small. Otherwise, a flexible [inflexible] technology becomes the firm's best option for intermediate level of debt financing while an inflexible [flexible] technology is again

[3] Maksimovic (1988) analyses the impact of debt on the possibilities to sustain collusion. Poitevin (1989, 1990) argues that debt may allow to signal low production cost. Glazer (1994) solves a two period model in which debt is repaid at the end of the last period; in the second period debt is pro-competitive but, in the first period, debt allows some kind of collusion because an increase in the rival's profit decreases its residual debt and make it less aggressive in the last period. Showalter (1995, 1999) analyses the Bertrand competition case; he shows that the optimal strategic debt choice depends on the type of uncertainty that exists 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 an entry framework, the incumbent wants to commit credibly to choose a low price in order to deter entry, hence to be in debt if costs are uncertain and debt free if demand is uncertain. 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) expands the model of Brander and Lewis (1988) by allowing corner solutions; with this specification, 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 destroy Brander and Lewis's (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. In Bolton and Scharfstein (1990), debt decreases the probability that the firm will survive and therefore increases the probability that rivals will prey on it.

[4] In contrast, Vives (1989) analyzes a model where flexibility, defined as a flatter marginal cost, is the source of commitment.

the firm's best option for high level of debt financing. Hence, the level of financial hardship has a non-monotonic effect on the level of investment: as the level of equity financing increases, 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 (no debt) firm. Moreover, we show that the level of external financing (debt) may be used strategically as a non-cooperative collusive way to increase the expected profits of both firms. A firm may also use debt as a commitment device to increase its own expected profit. Finally, we show that firms may find profitable to face larger bankruptcy costs because those costs modify their respective best reply functions and therefore may lead firms to more profitable technological equilibria.

The paper is organized as follows. We present the model in section 2. We derive in section 3 the profits of the firms for given technologies and we infer the competitive debt contracts. In section 4, we study the impact of debt on the technological flexibility choices. In section 5, we discuss the strategic value of debt and the jointly chosen capital and technological structures. We conclude in section 6.

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 α is a random variable taking two values, α_1 with probability μ and α_2 with probability $1 - \mu$, with $\alpha_2 > \alpha_1$.

Firms choose between two available 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 the sunk costs may differ. The sunk cost of an inflexible technology is K; this cost may be composed of product design costs, land purchases, plant construction

[5] Demand linearity and all the other specific assumptions such as constant marginal cost are made only to get tractable explicit solutions. The reader will understand that our assumptions could be relaxed at the cost of more complexity and less transparency in the results.

costs, fixed marketing cost, and so on. The sunk cost of a flexible technology is $K + H$ where $H \geq 0$. Hence, a firm choosing the flexible technology invests more.

Initially, entrepreneur $h \in \{1, 2\}$ has a capital of A_h, either equity or internal funds. 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 through debt (from a bank).[6] Banks can observe the technological flexibility choices of both firms but not the profits levels.[7] So a debt contract will specify a level of repayment R independent of the level of profit but dependent on the level of demand and on the 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. For matter of simplicity, we avoid introducing incentive constraints in the problem by assuming that in case of bankruptcy, courts can check the books of the firm, find the liars and impose on them harsh punishment.[8] We assume also that the banking sector is perfectly competitive: for each loan, the expected repayment is equal to the payoff obtained 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.

The two entrepreneurs begin the game with observable amounts of equity A_1 and A_2. The timing of the competition game is as follows. In the first stage, each entrepreneur jointly chooses her technology and negotiates her loan conditions and both entrepreneurs do it simultaneously. We model this as follows: first, entrepreneurs simultaneously negotiate debt contracts as *functions* of the technological configuration to emerge in the industry and second, they choose simultaneously their respective technology.[9] Hence the debt contracts and the technologies or

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

[7] This assumption of unobservability of profits is introduced so as to make the standard debt contract optimal. See Townsend (1979) and Bolton and Scharfstein (1990).

[8] In other words, profits are unobservable by banks but verifiable by courts, an assumption which can be justified by the relative investigation power of courts and banks.

[9] Clearly, debt contracts are not in practice a function of the technological configuration of the industry. But we can justify this modelization strategy 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 capacity installed at other firms

flexibility levels are chosen simultaneously within a firm and across firms. In the second stage, the entrepreneurs observe the level of demand and engage in Cournot competition. From the outcome of the second stage, firms repay debt or go bankrupt.

We will restrict our analysis to the more interesting cases by assuming (without loss of generality) that in the high state of demand, 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 equity, that is close to 0, goes bankrupt whatever its technology.[10] Firms may go bankrupt in the low state of demand according to the following three possible parameter configuration sets Ω_s with elements $\omega = (\alpha_1, c, \beta, x)$.

- $\Omega_1 \equiv \{\omega \mid x < (\alpha_1 - c)/2\beta\} \equiv \{\omega \mid \alpha_1 > 2\beta x + c\}$: The capacity of the inflexible technology is small relative to the size of the market under low demand implying that even under the bad conjuncture, 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 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 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.

This model is a simple and tractable strategic competition model capturing the relevant characteristics of the 'new' economy as discussed above, of the interdependence between finan-

in the industry and to the volatility of market conditions in order to credibly convince the bank of the level of profit it is likely to make in different scenarios and therefore of the risk it represents.

[10] In other words, the level of profit over variable cost a firm makes in the low state of demand is always less that the cost K or $K + H$ of the technologies.

cial structure and technology investment choice both in terms of type and level (endogenous cost function), and of debt contracting under asymmetric information (adverse selection) and bankruptcy cost.

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. For $t, t' \in \{i, f\}$ and any $\Omega \in \{\Omega_1, \Omega_2, \Omega_3\}$, 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 as a function of technological configurations and the parameter set Ω. The debt threshold over which the firm goes bankrupt is simply the profit level $\pi_1(t, t', \Omega)$. The Cournot equilibrium profits over operating costs, as functions of the technological choices of the firms, are derived in Appendix A.

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.[11] If debt D is less than $\pi_1(f, t', \Omega)$, the firm never goes bankrupt. Given that the banking sector is perfectly competitive, the repayment R_h is then simply equal to the amount borrowed $K + H - A_h$.

$$R_h = K + H - A_h. \tag{1}$$

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. 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')

[11] When a flexible firm faces an inflexible firm with a large capacity ($\omega \in \Omega_3$), the flexible firm may earn more profit when demand is low, in which case the inflexible firm shuts down and the flexible one is a monopolist, than when demand is high, in which case the inflexible firm captures a large market share. It may therefore happen that the flexible firm avoids bankruptcy when the demand is low but goes bankrupt when the demand is high ! We do not study such cases.

is given by:

$$R_h = \frac{1}{1-\mu}\left[K + H - A_h - \mu\pi_1(f, t', \Omega)\right]. \tag{2}$$

We see from (2) 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 (see footnote 8). We can obtain the expected profit as follows. For low debt levels, the firm never goes bankrupt and its expected profit is $\mu\pi_1(f, t', \Omega) + (1-\mu)\,\pi_2(f, t', \Omega) - R_h - A_h$ where R_h is given by (1). For large debt levels, the firm goes bankrupt if demand is low; its expected profit is $(1-\mu)\left[\pi_2(f, t', \Omega) - R_h\right] - \mu B - A_h$ where R_h is now given by (2). Thus, making use of (1) and (2), we obtain the expected profit of the entrepreneur:

$$E\Pi(f,\ t',\ \Omega) = \begin{cases} \widehat{E\Pi}\,(f, t', X)\,, & \text{if } K + H - A_h \leq \pi_1(f, t', \Omega) \\ \\ \widehat{E\Pi}\,(f, t', X) - \mu B, & \text{if } K + H - A_h > \pi_1(f, t', \Omega) \end{cases} \tag{3}$$

where $\widehat{E\Pi}\,(f, t', \Omega)$ is the expected profit when the firm's debt is low enough to avoid going bankrupt:

$$\widehat{E\Pi}\,(f, t', \Omega) = \left[\mu\pi_1(f, t', \Omega) + (1-\mu)\,\pi_2(f, t', \Omega)\right] - (K + H)\,. \tag{4}$$

The difference between the two profit levels is the expected bankruptcy cost. The expressions for $\pi_k(\cdot)$ and $\widehat{E\Pi}(\cdot)$ in the different relevant cases are derived in Appendix A.

3.2 Financial contract and expected profit of an inflexible firm

If either $\omega \in \Omega_1 \cup \Omega_3$ and $t' \in \{i, f\}$ or $\omega \in \Omega_2$ and $t' = f$, the gross profit of an inflexible firm is equal to $\pi_1(i, t', \Omega)$ when demand is low. If it has a debt D lower than this gross profit, it never goes bankrupt and $R_h = K - A_h$. Otherwise it goes bankrupt 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:

$$R_h = \frac{1}{1-\mu}\left[K - A_h - \mu\pi_1(i, t', \Omega)\right]. \tag{5}$$

Its expected profit is therefore given by

$$E\Pi\,(i, t', \Omega) = \begin{cases} \widehat{E\Pi}\,(i, t', X)\,, & \text{if } K - A_h \leq \pi_1(i, t', \Omega) \\ \\ \widehat{E\Pi}\,(i, t', X) - \mu B, & \text{if } K - A_h > \pi_1(i, t', \Omega) \end{cases} \tag{6}$$

where

$$\widehat{E\Pi}\left(i,t',\Omega\right)=\mu\pi_1(i,t',\Omega)+\left(1-\mu\right)\pi_2(i,t',\Omega)-K. \tag{7}$$

If $\omega\in\Omega_2$ and $t'=i$, only one firm produces if demand is low. We assume that the producing firm is determined randomly with probability 1/2. 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

$$R_h=\begin{cases}\dfrac{1}{1-\mu/2}\left(K-A_h\right), & \text{if } K-A_h<\pi_1(i,i,X_2)\\ \dfrac{1}{1-\mu}\left(K-A_h-\frac{1}{2}\mu\pi_1(i,i,\Omega_2)\right), & \text{otherwise.}\end{cases} \tag{8}$$

Making use of (8), we obtain the expected profit which is the same for both firms:

$$E\Pi\left(i,i,X_2\right)=\begin{cases}\widehat{E\Pi}\left(i,i,\Omega_2\right), & \text{if } K-A_h\leq 0\\ \widehat{E\Pi}\left(i,i,\Omega_2\right)-\frac{1}{2}\mu B, & \text{if } 0<K-A_h\leq\pi_1(i,i,\Omega_2)\\ \widehat{E\Pi}\left(i,i,\Omega_2\right)-\mu B, & \text{if } K-A_h>\pi_1(i,i,\Omega_2)\end{cases} \tag{9}$$

where

$$\widehat{E\Pi}\left(i,i,X_2\right)=\mu\frac{1}{2}\pi_1(i,i,\Omega_2)+\left(1-\mu\right)\pi_2(i,i,\Omega_2)-K. \tag{10}$$

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 cost of the technology it chooses, either K or $K+H$, minus its internal 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.[12] If there

[12]Bankruptcy costs allow a standard debt contract to be an elegant and simple solution to the adverse selection problem raised by the unobservability of profit. Without that agency problem, the optimal financing contract would be a profit sharing contract under which the firm would never go bankrupt.

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 choice being independent of its capital structure.[13] 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 the investment cost of its technology and its equity or liquidity level A. Ceteris paribus, large values of B combined with low levels of A will 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. The critical levels of B and H will depend on Ω, that is on the capacity of the inflexible technology compared to the size of the market under low demand. The characterization of best reply functions is expressed below in terms of H and B being large or not; the critical levels of H and B depend on the parameter set Ω considered. When $\Omega \in \{\Omega_1,\ \Omega_3\}$, H is large [small] if it is larger [smaller] than the profit differential under low demand $\pi_1(f,i,\Omega) - \pi_1(i,i,\Omega)$ and B is large [small] if it is larger [smaller] than the absolute value of the profit differential of the technologies for all equity firms $|\widehat{E\Pi}(i,i,\Omega) - \widehat{E\Pi}(f,i,\Omega)|$. When $\Omega = \Omega_2$, H is large if it is larger than the profit level $\pi_1(f,i,\Omega)$, small if it is smaller than $\pi_1(i,i,\Omega)$ and intermediate if it is in between those two profit levels. In the first two cases, B is large if and only if it is larger than $|\widehat{E\Pi}(i,i,\Omega) - \widehat{E\Pi}(f,i,\Omega)|$ as before while in the last case B is large if and only if it is larger than twice that critical value. With these benchmarks in mind, we can characterize the best response to inflexibility and flexibility.

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

Suppose that a firm's competitor has the inflexible technology. To determine the firm's best response, we must determine the value of its expected profit differential $E\Pi(i,i,\Omega) - E\Pi(f,i,\Omega)$, 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

[13] The result can be seen directly from expressions (13) to (17) in Appendix B.

its technology.[14] 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 and independent of the expected cost of bankruptcy μB. For intermediate levels of equity, whether or not a firm goes bankrupt in the low state of demand will depend on its technology. Therefore, its best response will depend on the expected bankruptcy cost μB. 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 iff 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 iff 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 (3) and (19), we obtain the following two propositions.

Proposition 1 *When inflexibility is the best response to inflexibility for an all equity firm, it remains the best response for all levels of equity if either H is large or B is small; otherwise, that is if either H is small and B is large or H is intermediate and B is large,*[15] *it is the best response for low and high levels of equity while flexibility becomes the best response for intermediate levels.*[16]

Proposition 2 *When flexibility is the best response to inflexibility for an all equity firm, it remains the best response for all levels of equity if either H is small or B is small; otherwise, that is if either H is large and B is large or H is intermediate and B is large, it is the best response for low and high levels of equity while inflexibility becomes the best response for intermediate levels.*[17]

These results are quite intuitive. When inflexibility is the best response to inflexibility for an all equity firm, that is $\widehat{E\Pi}(i,i,\Omega) > \widehat{E\Pi}(f,i,\Omega)$, it will remain the best response for all levels

[14] 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.

[15] The latter case appearing only if $\omega \in \Omega_2$.

[16] The levels of equity for which flexibility is the best response are given by $A_h \in (A(f,i,\Omega_2),\ K)$ or $A_h \in (A(f,i,\Omega_2),\ A(i,i,\Omega_2))$ according to whether $\widehat{E\Pi}(i,i,\Omega_2) - \widehat{E\Pi}(f,i,\Omega_2)$ is smaller than $\frac{1}{2}\mu B$ or in the interval $(\frac{1}{2}\mu B,\ \mu B)$.

[17] The levels of equity for which inflexibility is the best response are given by $A_h \in (A(i,i,\Omega_2),\ A(f,i,\Omega_2)$ or $A_h \in (A(i,i,\Omega_2),\ K)$ according to whether $\widehat{E\Pi}(f,i,\Omega_2) - \widehat{E\Pi}(i,i,\Omega_2)$ is larger than μB or in the interval $(\frac{1}{2}\mu B,\ \mu B)$.

of equity if the incremental cost H of switching to a flexible technology is large or if that cost is small or intermediate but the cost of bankruptcy is small, in which cases it is not interesting to invest in the more costly technology and/or give up profitable market opportunities simply to try to avoid bankruptcy. However, when the differential investment cost between an inflexible technology and a flexible one is small or intermediate and the cost of bankruptcy is large, then the firm will prefer to give up some market share and profit in order to avoid the costly bankruptcy which from (14) and (17) will occur in the low state of demand if the firm's level of equity is intermediate and it is endowed with the inflexible technology but not if it is endowed with the flexible technology. Hence the valuable switch to the more costly flexible technology in those cases: the level of investment is the same for low and high levels of equity or internal financing, that is for firms that either face a severe financial constraint or face no financial constraint, and higher than for intermediate level of financial hardship. Hence, the level of investment is a non-monotonic function of the internal liquidity level, the firms facing either severe financial constraints or no constraint at all investing *less* than the firms facing 'intermediate' financial hardship.

When investing in a flexible technology is the best response to the competitor's inflexible technology for an all equity firm, that is $\widehat{E\Pi}(i,i,\Omega) < \widehat{E\Pi}(f,i,\Omega)$, it will remain the best response for all levels of equity if the investment saving from switching to an inflexible technology, that is H here, is small or if that cost is large or intermediate but the cost of bankruptcy is small. In those cases it is not interesting to switch to the less costly inflexible technology and give up profitable market opportunities simply to try to avoid bankruptcy. However, when the differential investment cost H is large or intermediate and the cost of bankruptcy is large, then the firm will prefer to give up some market share and profit in order to avoid the costly bankruptcy which from (13), (15) and (16) will occur in the low state of demand if the firm's level of equity is intermediate, that is between $A(i,i,\Omega)$ and $A(f,i,\Omega)$ in this case, and the firm is endowed with the flexible technology, but not if it is endowed with the inflexible technology. Hence the valuable switch to the inflexible technology in those cases: the level of investment is the same for low and high levels of financial hardship and lower than for intermediate level of financial hardship. Hence, the level of investment is a non-monotonic function of the internal liquidity level, the firms facing either severe financial constraints or no constraint at all investing significantly *more* than the firms facing 'intermediate' financial hardship.

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 technology whereas the other firm is a flexible firm, that is:

$$A(i, f, \Omega) = K - \pi_1(i, f, \Omega) \;\; ; \;\; A(f, f, \Omega) = K + H - \pi_1(f, f, \Omega). \tag{11}$$

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

Proposition 3 *When flexibility is the best response to flexibility for an all equity firm, it remains the best response for all levels of equity if either H is small or B is small; otherwise, that is if H is large and B is large, it is the best response for low and high levels of equity while inflexibility becomes the best response for intermediate levels.*

Proposition 4 *When inflexibility is the best response to flexibility for an all equity firm, it remains the best response for all levels of equity if either H is large or B is small; otherwise, that is if H is small and B is large, it is the best response for low and high levels of equity while flexibility becomes the best response for intermediate levels.*

The intuition for those results is the following. When flexibility is the best response to flexibility for an all equity firm, the best response will change as the level of equity increases if the investment saving from switching to a less costly inflexible technology is large and the cost of bankruptcy is large. In those cases it is better for the firm to switch to the less costly technology even if it then gives up profitable market opportunities because in doing so it can avoid a costly bankruptcy. We therefore find that the level of investment is the same for low and high levels of equity or internal financing, that is for firms that either face a severe financial constraint or face no financial constraint, and larger than for intermediate level of financial hardship. 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 the differential investment cost is small and the expected bankruptcy cost is large, we find that the level of investment is the same for low and high levels of equity or internal financing and smaller than for intermediate level of financial hardship. Hence, the level of investment is again a non-monotonic function of the internal liquidity level, 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

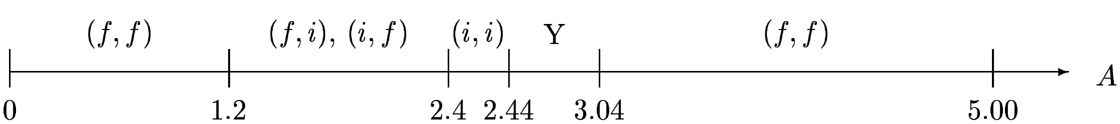
Rather than proceed with a complete analytical characterization of equilibrium technological configurations, we present in this section some simple numerical examples which will prove sufficient to show how the above best response functions generate equilibrium technological configurations in the industry as functions of the equity or internal liquidity levels of the firms. The examples are worked out in Appendix C.

Example 1 ($\omega \in \Omega_1$):

$$\mu = 0.5,\ \alpha_1 = 5,\ \alpha_2 = 10,\ x = 2,\ \beta = 1,\ c = 0.2,\ K = 4,\ H = 1,\ B = 2.$$

We consider first a common equity 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 (example 1)
[in Y, (f, f) and (i, i)]



If the common equity level is relatively high ($A \geq 3.04$), in particular if it can cover the cost of both technologies ($A \geq 5$), both firms choose the more costly flexible technology in equilibrium. If $2.44 < A < 3.04$, there are two Nash equilibria in which both firms choose the same technology, either the flexible or the inflexible one. In this interval of equity levels, the firms may fall into a flexibility trap since (i, i) is more profitable for both firms (see Appendix C). If $2.4 < A < 2.44$, the unique equilibrium is (i, i). If $1.2 < A < 2.4$, the equilibrium is asymmetric, (f, i) or (i, f); hence, although both firms have the same internal liquidity, they choose different technologies and invest different amounts. Finally, if the common equity level is small ($A < 1.2$), the equilibrium is again (f, f). In this example, firms invest more in equilibrium if they face either no financial constraint 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.[18]

Insert Figure $1'$ here

There are values for which the unique equilibrium is asymmetric, (f, i) or (i, f). There are also 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 a non-monotonic function of its equity level, given the equity level of its competitor: for example, if A_2 is in the interval $(0,\ 1.2)$, the equilibria are such that firm 1 invests in the more costly flexible technology if its equity level is small, that is if $A_1 \in (A_2,\ 1.2)$, in the less costly inflexible technology for intermediate equity levels, that is for $A_1 \in (1.2,\ 2.44)$, and again in the flexible technology if its equity level is large, that is if $A_2 \in (2.44,\ 5)$. Hence, the equilibrium investment level of a firm is a non-monotonic function of its index 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.[19] As leverage of firm 1 goes down around $A_1 = 1.2$, its investment level goes down too. One can also observe that the technological choice of a firm is a non-monotonic function of the equity level of its competitor, given its own equity level. But Figure $1'$ illustrates that in general but not always the higher equity financed firm 1 opts in equilibrium for an investment level similar to or higher than the investment level of its more leveraged competitor.

[18]The reader will have observed that Figure 1 illustrating the case $A_1 = A_2$ is indeed the diagonal of Figure $1'$.

[19]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 as the average of the first two columns of Table III(B) of Rajan and Zingales (1995).

When firms are totally financed by equity, they both choose the flexible technology. 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 higher investment outlay and a lower profit when demand is low. If equity is reduced and borrowing becomes necessary, a flexible firm may go bankrupt if the demand is low. It can eliminate this risk if it chooses the inflexible technology, allowing a reduction in the amount borrowed 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 variance of profit decrease. These effects explain the switch in equilibrium from (f, f) to (f, i) when the equity of firm 1 decreases.

But the technological switch of firm 2 may also make the flexible technology of the other firm more risky. When firm 2 becomes inflexible, the expected value and variance of profit for the flexible firm 1 increase. This may send the firm into bankruptcy if demand is low. By choosing an inflexible technology, the firm can reduce the variance of its profit. This explains the existence of two equilibria in zone Y of Figure 1 and of a unique equilibrium (i, i) in the hatched zone. When firms have very low equity, a change in technology is insufficient to eliminate the probability of bankruptcy. The previous effect disappears and both firms choose again the more expensive flexible technology. Hence, when the capacity of the inflexible technology is low ($\omega \in \Omega_1$), the presence of an intermediate level of debt favors smaller investments into inflexible technologies because they are less risky, the variance of profit being lower, but the existence of a high level of debt favors larger investments into flexible technologies because bankruptcy cannot be avoided when demand is low.

This example is very instructive. It shows that the technological flexibility choices of the firms depend on their level of equity or internal liquidity. Hence, on two perfectly identical markets, the technological choices may differ if the firms have different internal liquidity levels or different access to equity financing. They may also differ even if they have the same level of equity, for example if $A_1 = A_2 \in (1.2,\ 2.4)$. 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.

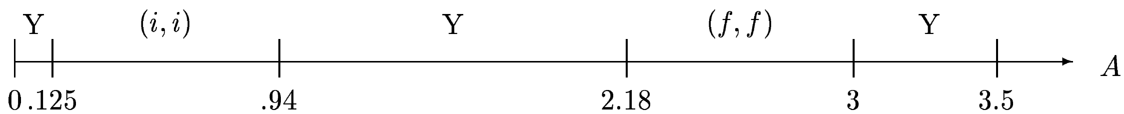
Example 2 ($\omega \in \Omega_2$):

$$\mu = 0.5,\ \alpha_1 = 5,\ \alpha_2 = 10,\ x = 2.5,\ \beta = 1,\ c = 0.2,\ K = 3,\ H = 0.5,\ B = 6.$$

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

FIGURE 2 (example 2)

[in Y, (f, f) and (i, i)]



If both firms are all equity firms ($A \geq 3.5$), there are two equilibria (f, f) and (i, i), so that the firms may fall into a flexibility trap since (i, i) would be more profitable for both of them. If the common equity level decreases below 3, then (f, f) becomes the unique equilibrium. If equity decreases even more, we have again two equilibria (f, f) and (i, i) but, contrary to the first situation, profits are now higher in the (f, f) equilibrium. The firms may here fall into an inflexibility trap. A further decrease in equity levels brings (i, i) as the unique equilibrium. Finally, if the firms have close to zero equity, there are again two equilibria (f, f) and (i, i) with the latter being more profitable for both firms.

When the equity levels differ, other equilibria appear (see Figure 2$'$).

Insert Figure 2$'$ here

Again, the observation of demand and cost conditions in an industry is not sufficient to predict which technological configuration will emerge. If the firms are almost totally financed by equity, there are two technological equilibrium configuration: (f, f) and (i, i). The existence of these two pure strategies 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 strategic effects: the firm commits herself 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 the demand is high. In this context, flexibility has a positive strategic value. When demand is low the opposite effect arises and flexibility has a negative strategic value. For the parameter values of example 2, the net strategic value of flexibility is positive. When a firm adopts the flexible technology, the value of flexibility increases for the other firm as well. This effect explains the existence of the two pure strategy equilibria.[20]

Suppose that the equilibrium technological configuration is (i, i) at point a in Figure $2'$. And suppose that the equity of firm 2 decreases to some level in the interval (2.18, 3.00). The firm must borrow additional funds and may end up bankrupt (with probability 1/2) when demand is low if it sticks to the technological configuration (i, i). By switching to flexibility, the firm already in debt must borrow even more to finance the higher investment cost of the flexible technology. But its increase in profit when demand is low is more important and eliminates the risk of bankruptcy. When the higher leveraged firm changes its technology, the other firm is induced to change its technology too: there is a unique equilibrium technological configuration (f, f).

Hence, when the capacity of the inflexible technology is intermediate, the equilibrium technological configuration can evolve toward more flexibility or more inflexibility as leverage increases because the level of risk linked to a technology depends on the technology chosen by the other firm. However, in this example the firm with the larger equity financing (firm 1) always invests more in equilibrium than its competitor.

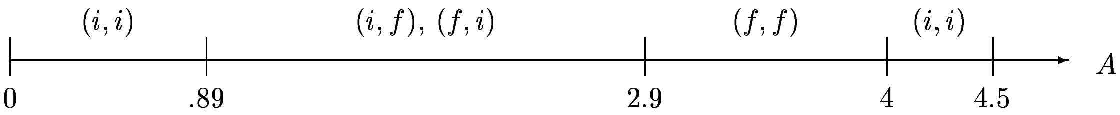
Example 3 ($\omega \in \Omega_3$):

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

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

[20] For more on the strategic value of technological choices, see Boyer, Jacques and Moreaux (2000).

FIGURE 3 (example 3)



As in the preceding two examples, the equilibrium technological configuration is changing with the equity levels. When the levels of equity are the same for both firms, $A_h = A,\ h = 1, 2$, 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. The case of asymmetric equity positions is illustrated in Figure $3'$.

Insert Figure $3'$ here

In this example, the capacity of the inflexible technology is so high ($x \in \Omega_3$) 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. A leveraged firm then prefer to switch to a flexible technology, thereby eliminating the risk of bankruptcy. When the firm's debt 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 when $A_1 > 4$, if may choose the inflexible technology to gain a commitment advantage on the product markets. 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 borrowed capital.[21]

We can conclude this section 4 by saying that the impact of equity financing on the technological configuration of an industry is a rather subtle non-monotonic one combining decision

[21] Similar equilibria appear in the cases illustrated in Figures 4 and 5.

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 because the relationship between the two levels is non-monotonic.

5 The strategic value of equity

The fact that the level of equity, 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 devices. Hence it is the pair $(A_h,\ B)$ which has a strategic value. In order to appreciate the competitive potential in an industry, we have to look at what could be called the industry 'commitment index', a function of both the equity financing and the bankruptcy cost.

5.1 Debt financing as a commitment device

In the previous section we assumed that A_h, the capital invested in his business by entrepreneur h, was his given initial wealth and that because of the agency problem, the entrepreneur could not raise additional funds through external equity. We relax that assumption in this section. We will assume 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 chosen technology, the firm must borrow. We show next that there exist cases in which the entrepreneurs decide to finance their firms in part through borrowing 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 1.62 even if in the technological configuration (i, i) their common expected profit would be higher at 2.6 (See Appendix C). When the firms are all equity financed, they play a prisoner dilemma game. If they decrease their equity capital, they alter the payoff matrix and they avoid the dilemma. In example 1, if both firms have an equity capital of $A = 3$, they play a subgame admitting (f, f)

and (i, i) as equilibria and they never go bankrupt. For even lower equity capital, the firms can reach the unique equilibrium configuration (i, i) which is better for them than (f, f). 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 buy the flexible technology, it goes bankrupt when demand is low. The expected bankruptcy cost 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:[22] debt has a strategic value in this context.

In example 2 (Figure 2′), the best technological configuration for the firms is (i, i) with financing mainly through equity $A_h > 3$. This equilibrium (i, i) is not unique and there is a flexibility trap here. A lower level of equity would eliminate this trap but one of the two firms would then go bankrupt when demand is low. The bankruptcy cost makes this strategy unattractive. So the firms will choose not to borrow. However debt may have a strategic value as in the following example 4 with its equilibrium technological configurations depicted in Figure 4.

Example 4 ($\omega \in \Omega_2$):

$$\mu = 0.5,\ \alpha_1 = 5,\ \alpha_2 = 10,\ x = 4,\ \beta = 1,\ c = 0.2,\ K = 2.5,\ H = 0.1, B = 3.$$

If the firms are all equity firms, the unique equilibrium is (i, i), even if firms would earn greater profits in the technological configuration (f, f), hence a kind of inflexibility trap here. If the firms cut down their equity capital to $A_h = 2.45$, the equilibrium of the following subgame becomes (f, i) or (i, f) and the sum of profits increases. But these equity levels are not an equilibrium of the preliminary stage game. A firm would deviate to be an all equity firm. On the other

[22] The firms would be better off eliminating the configuration (f, f) as an equilibrium by reducing even more their equity capital but such capital structures are not equilibria of the preliminary stage game: a firm would be better off deviating and increasing its equity capital to $A_h = 4$ to induce the configuration (f, i) as the unique equilibrium. If firms were choosing their capital structure sequentially, a form of coordination among firms, they would avoid this problem. The leader would then choose $A_1 = 3$ and the follower $A_2 = 2.42$ with the unique technological equilibrium being (i, i). In this configuration, the firms never go bankrupt. So raising borrowed capital has no cost.

hand, firms can increase their expected profits by cutting down sharply their equity capital to say $A_h = 0.8$; the subgame then admits two equilibria (f, f) and (i, i). In the latter equilibrium, one firm goes bankrupt when demand is low. In the former one, firms never go bankrupt. If the two equilibria have the same probability, the expected payoff of firms increases. Furthermore, these are equilibrium capital structures. Debt can again increase the expected profits of both firms.

Insert Figure 4 here

Last, let us consider the following example 5 for the case of a large capacity level of the inflexible technology with its equilibrium technological configurations depicted in Figure 5.

Example 5 ($\omega \in \Omega_3$):

$$\mu = 0.3,\ \alpha_1 = 5,\ \alpha_2 = 18,\ x = 6,\ \beta = 1,\ c = 0.2,\ K = 4,\ H = 0.75,\ B = 3.$$

In this example one firm can choose to be an all equity firm with the inflexible technology; the other firm then chooses $A_h \in (2.2,\ 4)$ together with the flexible technology. The more profitable firm is the flexible firm. Debt allows the firm to select the most profitable technology. In example 3 ($\omega \in \Omega_3$), the capital structure could be used strategically to increase the expected profits of both firms. In example 5 ($\omega \in \Omega_3$), the capital structure is used strategically by one firm to increase its expected profit at the expense of the other.[23]

Insert Figure 5 here

Clearly, whatever the capacity level of the inflexible technology, there exist subsets of parameter values for which the equilibrium capital structures combine equity and debt. In these

[23]The strategic commitment value of issuing debt is emphasized when the firms choose their technologies sequentially. If the two firms are all equity firms, the leader chooses flexibility and the follower chooses inflexibility with payoffs of 21.35 and 20.78 respectively. However, by choosing $A_2 = 3$, the follower changes its best reply to flexibility in the following stage. If the leader chooses flexibility, the follower then chooses flexibility too with payoff of 20.66 for both. The leader then prefers inflexibility and the follower chooses flexibility with payoffs of 20.78 and 21.35 respectively. The follower, by issuing debt, can outperform the leader in terms of profit. There is another perfect equilibrium in which the leader chooses $A_h \in (2.2,\ 4)$ with the flexible technology and the follower is an all equity firm with the inflexible technology; but, in the first stage, the leader plays a weakly dominated strategy. See Ellingsen (1995) for an analysis of games with a similar structure although in a different context.

equilibria, the debt is used strategically to modify the equilibrium technological configuration of the industry which would have emerged had the entrepreneurs decided to finance their firms through equity only.

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 induce banks to ask for those collateral assets.[24] 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, 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 difference. However Williamson (1983, 1985) 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 another explanation for this kind of behavior. Increasing the difference of evaluation increases the bankruptcy cost for the borrower and so increases the commitment power of debt. We find in Shakespeare, *The merchant of Venice* $[I, 3]$, an extreme example of the this type of debt contract:

[24] See Freixas and Rochet (1997, chapters 4 and 5) for references.

"*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,
And say there is much kindness in the Jew."

6 Conclusion

The bankruptcy costs and the equity levels of firms have significant impacts on the equilibrium technological configurations in an industry. These effects arise because indebted firms, either flexible or inflexible, may want to change their technologies to reduce the probability of bankruptcy. When the capacity level associated with the inflexible technology is low relative to the size of the market under low demand, the equilibrium technological configuration of the industry is more inflexible if firms have moderate levels of equity than if they are whole equity firms (Figure 1). When that capacity level is large, moderate levels of equity make the technological configuration of the industry more flexible (Figure 3). The effect of equity is non-monotonic. An industry may have the same technology equilibrium for low and high leverage levels, with a different technology equilibrium for intermediate leverage levels.

The endogeneity of technological choices is likely to be an important determinant of the optimal capital structure and of the relationship between capital structure and product market competition. Our results allow us to take some steps in characterizing the role of endogenous technology choices, whose analysis has been somewhat neglected so far.

The main determinants of capital structure, as modeled and identified in the literature, can be regrouped under four major headings: taxation, information asymmetries together with conflicts of interest, competitive positioning and finally corporate control.[25] In order to determine the optimal combination between debt and equity, firms must consider simultaneously these determinants. The significance of each determinant depends on the specific environment of the firm.

As mentioned in the introduction, 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 investment stage. It complements the analysis of Fazzari, Hubbard and Petersen (1988), Kaplan and Zingales (1997) and Cleary (1999) among others who study 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. 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 soften by more sophisticated managerial contracts and the likelihood of a hostile takeover can be reduced by a strategic allocation of voting rights. For some market contexts or industry parameters, debt has a 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. Example 2 illustrates this last point: debt can solve the coordination problem due to multiple equilibrium technological configurations but may lead to the selection of a Pareto-dominated equilibrium.

According to Brander and Lewis (1986), the output level increases with the debt level whereas in Glazer (1994), the output level decreases in the first period and increases in the second period as debt increases. 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. In our model, the link between debt levels and output levels is more subtle since debt not only induces changes in output and prices given the technologies but also changes in the technologies

[25] See for instance the recent contributions of Harris and Raviv (1991), Hart (1995), Rajan and Zingales (1995), Leland and Toft (1996).

themselves. In example 1 above, a switch from (f, f) to (i, i) increases output if demand is low but decreases output if demand is high. In example 2, the same switch decreases output in the two states of demand.

It is nevertheless possible to draw some general results. If the market size is large relative to the capacity of the inflexible technology, leveraged firms will rather invest in inflexible technologies resulting in less variability in industry output but more variability in prices. If the market size is small relative to the capacity of the inflexible technology, opposite effects emerge. In the intermediate case, both situations are possible depending on the industry parameters. Therefore, the effects characterized by Brander and Lewis (1986), Glazer (1994) and Showalter (1995) depend closely on the 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 –, the impacts of debt become more subtle and in general non-monotonic.

The non-monotonicity of the relationship between the firm's equity level, which in our simplified model represents the level of internal financing and the creditworthiness of the firm, and its level of investment in different types of technologies, in particular the fact that this relationship may be $\bigcap$-shaped or $\bigcup$-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 $\bigcup$-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) if the aggregation over firms is such that the number of firms behaving that way turns out to be important enough. On the other hand, if enough firms find themselves in a $\bigcap$-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 small step in trying to explain those conflicting empirical regularities. We like to think that our results contributes also to our understanding of the complex interconnections between capital structure, technological flexibility and strategic market behavior.

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 α, the Cournot reaction function of a flexible firm h is $q_h = \frac{1}{2}\left((\alpha - c)/\beta - q_j\right),\ j \neq h$.

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
$\widehat{E\Pi}(f, f, \Omega_1) = \frac{1}{9\beta}\left[\mu\,(\alpha_1 - c)^2 + (1-\mu)\,(\alpha_2 - c)^2\right] - (K + H)$
- if one firm is flexible and the other is inflexible, the production level of the flexible [inflexible] firm is $\frac{1}{2}\left((\alpha_k - c)/\beta - x\right)$ [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
$\widehat{E\Pi}(f, i, \Omega_1) = \frac{1}{4\beta}\left[\mu\,(\alpha_1 - c - \beta x)^2 + (1-\mu)\,(\alpha_2 - c - \beta x)^2\right] - (K + H)$,
$\widehat{E\Pi}(i, f, \Omega_1) = \frac{1}{2}\left[\mu\alpha_1 + (1-\mu)\,\alpha_2 - c - \beta x\right]x - K$
- 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
$\widehat{E\Pi}(i, i, \Omega_1) = \left[\mu\alpha_1 + (1-\mu)\,\alpha_2 - c - 2\beta x\right]x - K$

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
$\widehat{E\Pi}(i, i, \Omega_2) = \mu\frac{1}{2}\,(\alpha_1 - c - \beta x)\,x + (1-\mu)\,(\alpha_2 - c - 2\beta x)\,x - K.$

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

– for (i,i), both firms shut down when demand is low and the expected profit of each firm is given by (6) with
$\widehat{E\Pi}(i,i,\Omega_3) = (1-\mu)\,(\alpha_2 - c - 2\beta x)\,x - K$.

B Best response in technology

Best reply to inflexibility

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 Ω.[26] This assumption is made only to simplify the presentation of the different cases, without any loss of generality.

$$\begin{aligned} A(i,i,\Omega) &= K - \pi_1(i,i,\Omega) > 0 \\ A(f,i,\Omega) &= K + H - \pi_1(f,i,\Omega) > 0 \end{aligned} \tag{12}$$

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 inflexibility 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 inflexibility*:

[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:

$$
\begin{aligned}
\widehat{E\Pi}(i,i,\Omega) - \mu B &\geq \widehat{E\Pi}(f,i,\Omega) - \mu B, &&\text{for } A_h < A(i,i,\Omega) \\
\widehat{E\Pi}(i,i,\Omega) &\geq \widehat{E\Pi}(f,i,\Omega) - \mu B, &&\text{for } A(i,i,\Omega) < A_h < A(f,i,\Omega) \\
\widehat{E\Pi}(i,i,\Omega) &\geq \widehat{E\Pi}(f,i,\Omega), &&\text{for } A(f,i,\Omega) < A_h
\end{aligned}
\tag{13}
$$

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

$$
\begin{aligned}
\widehat{E\Pi}(i,i,\Omega) - \mu B &\geq \widehat{E\Pi}(f,i,\Omega) - \mu B, &&\text{for } A_h < A(f,i,\Omega) \\
\widehat{E\Pi}(i,i,\Omega) - \mu B &\geq \widehat{E\Pi}(f,i,\Omega), &&\text{for } A(f,i,\Omega) < A_h < A(i,i,\Omega) \\
\widehat{E\Pi}(i,i,\Omega) &\geq \widehat{E\Pi}(f,i,\Omega), &&\text{for } A(i,i,\Omega) < A_h.
\end{aligned}
\tag{14}
$$

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:

$$
\begin{aligned}
\widehat{E\Pi}(i,i,\Omega_2) - \mu B &> \widehat{E\Pi}(f,i,\Omega_2) - \mu B, &&\text{for } A_h < A(i,i,\Omega_2) \\
\widehat{E\Pi}(i,i,\Omega_2) - \tfrac{1}{2}\mu B &> \widehat{E\Pi}(f,i,\Omega_2) - \mu B, &&\text{for } A(i,i,\Omega_2) < A_h < K \\
\widehat{E\Pi}(i,i,\Omega_2) &> \widehat{E\Pi}(f,i,\Omega_2) - \mu B, &&\text{for } K < A_h < A(f,i,\Omega_2) \\
\widehat{E\Pi}(i,i,\Omega_2) &> \widehat{E\Pi}(f,i,\Omega_2), &&\text{for } A(f,i,\Omega_2) < A_h
\end{aligned}
\tag{15}
$$

- 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

$$
\begin{aligned}
\widehat{E\Pi}(i,i,\Omega_2) - \mu B &> \widehat{E\Pi}(f,i,\Omega_2) - \mu B, &&\text{for } A_h < A(i,i,\Omega_2) \\
\widehat{E\Pi}(i,i,\Omega_2) - \tfrac{1}{2}\mu B &> \widehat{E\Pi}(f,i,\Omega_2) - \mu B, &&\text{for } A(i,i,\Omega_2) < A_h < A(f,i,\Omega_2) \\
\widehat{E\Pi}(i,i,\Omega_2) - \tfrac{1}{2}\mu B &> \widehat{E\Pi}(f,i,\Omega_2), &&\text{for } A(f,i,\Omega_2) < A_h < K \\
\widehat{E\Pi}(i,i,\Omega_2) &> \widehat{E\Pi}(f,i,\Omega_2), &&\text{for } K < A_h
\end{aligned}
\tag{16}
$$

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

$$\begin{aligned}
\widehat{E\Pi}(i,i,\Omega_2) - \mu B &> \widehat{E\Pi}(f,i,\Omega_2) - \mu B, && \text{for } A_h < A(f,i,\Omega_2) \\
\widehat{E\Pi}(i,i,\Omega_2) - \mu B &> \widehat{E\Pi}(f,i,\Omega_2), && \text{for } A(f,i,\Omega_2) < A_h < A(i,i,\Omega_2) \\
\widehat{E\Pi}(i,i,\Omega_2) - \tfrac{1}{2}\mu B &> \widehat{E\Pi}(f,i,\Omega_2), && \text{for } A(i,i,\Omega_2) < A_h < K \\
\widehat{E\Pi}(i,i,\Omega_2) &> \widehat{E\Pi}(f,i,\Omega_2), && \text{for } K < A_h
\end{aligned} \tag{17}$$

Best reply to flexibility

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

$$\begin{aligned}
A(i,f,\Omega) &= K - \pi_1(i,f,\Omega) > 0 \\
A(f,f,\Omega) &= K + H - \pi_1(f,f,\Omega) > 0
\end{aligned} \tag{18}$$

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: $A(i,f,\Omega_1) = A(i,f,\Omega_2) = K - \frac{1}{2}(\alpha_1 - c - \beta x)x$, $A(f,f,\Omega_1) = A(f,f,\Omega_2) = A(f,f,\Omega_3) = K + H - (\alpha_1 - c)^2/9\beta$, $A(i,f,\Omega_3) = K$. *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:

$$\begin{aligned}
\widehat{E\Pi}(i,f,\Omega) - \mu B &\geq \widehat{E\Pi}(f,f,\Omega) - \mu B, && \text{for } A_h < A(i,f,\Omega) \\
\widehat{E\Pi}(i,f,\Omega) &\geq \widehat{E\Pi}(f,f,\Omega) - \mu B, && \text{for } A(i,f,\Omega) < A_h < A(f,f,\Omega) \\
\widehat{E\Pi}(i,f,\Omega) &\geq \widehat{E\Pi}(f,f,\Omega), && \text{for } A(f,f,\Omega) < A_h
\end{aligned} \tag{19}$$

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

$$\begin{aligned}
\widehat{E\Pi}(i,f,\Omega) - \mu B &\geq \widehat{E\Pi}(f,f,\Omega) - \mu B, && \text{for } A_h < A(f,f,\Omega) \\
\widehat{E\Pi}(i,f,\Omega) - \mu B &\geq \widehat{E\Pi}(f,f,\Omega), && \text{for } A(f,f,\Omega) < A_h < A(i,f,\Omega) \\
\widehat{E\Pi}(i,f,\Omega) &\geq \widehat{E\Pi}(f,f,\Omega), && \text{for } A(i,f,\Omega) < A_h.
\end{aligned} \tag{20}$$

C Examples used in the text

Example 1: $\mu = 0.5$, $\alpha_1 = 5$, $\alpha_2 = 10$, $x = 2$, $\beta = 1$, $c = 0.2$, $K = 4$, $H = 1$ and $B = 2$.

Profit levels:

$$\begin{array}{lcccccc}
3.04 \leq A_h & E\Pi\left(f,f\right) & = & 1.62 & > & E\Pi\left(i,f\right) & = & 1.30 \\
 & E\Pi\left(f,i\right) & = & 3.59 & > & E\Pi\left(i,i\right) & = & 2.60 \\
 \\
2.44 \leq A_h < 3.04 & E\Pi\left(f,f\right) & = & 1.62 & > & E\Pi\left(i,f\right) & = & 1.30 \\
 & E\Pi\left(f,i\right) & = & 2.59 & < & E\Pi\left(i,i\right) & = & 2.60 \\
 \\
2.4 \leq A_h < 2.44 & E\Pi\left(f,f\right) & = & 0.62 & < & E\Pi\left(i,f\right) & = & 1.30 \\
 & E\Pi\left(f,i\right) & = & 2.59 & < & E\Pi\left(i,i\right) & = & 2.60 \\
 \\
1.2 \leq A_h < 2.4 & E\Pi\left(f,f\right) & = & 0.62 & < & E\Pi\left(i,f\right) & = & 1.30 \\
 & E\Pi\left(f,i\right) & = & 2.59 & > & E\Pi\left(i,i\right) & = & 1.60 \\
 \\
A_h < 1.2 & E\Pi\left(f,f\right) & = & 0.62 & > & E\Pi\left(i,f\right) & = & 0.30 \\
 & E\Pi\left(f,i\right) & = & 2.59 & > & E\Pi\left(i,i\right) & = & 1.60
\end{array}$$

Example 2: $\mu = 0.5$, $\alpha_1 = 5$, $\alpha_2 = 10$, $x = 2.5$, $\beta = 1$, $c = 0.2$, $K = 3$, $H = 0.5$ and $B = 6$.

Profit levels:

$$\begin{array}{lcccccc}
3 \leq A_h & E\Pi\left(f,f\right) & = & 3.11 & > & E\Pi\left(i,f\right) & = & 3.00 \\
 & E\Pi\left(f,i\right) & = & 3.82 & < & E\Pi\left(i,i\right) & = & 4.44 \\
 \\
2.18 \leq A_h < 3 & E\Pi\left(f,f\right) & = & 3.11 & > & E\Pi\left(i,f\right) & = & 3.00 \\
 & E\Pi\left(f,i\right) & = & 3.82 & > & E\Pi\left(i,i\right) & = & 2.94 \\
 \\
0.94 \leq A_h < 2.18 & E\Pi\left(f,f\right) & = & 3.11 & > & E\Pi\left(i,f\right) & = & 3.00 \\
 & E\Pi\left(f,i\right) & = & 0.82 & < & E\Pi\left(i,i\right) & = & 2.94 \\
 \\
0.125 \leq A_h < 0.94 & E\Pi\left(f,f\right) & = & 0.11 & < & E\Pi\left(i,f\right) & = & 3.00 \\
 & E\Pi\left(f,i\right) & = & 0.82 & < & E\Pi\left(i,i\right) & = & 2.94 \\
 \\
A_h < 0.125 & E\Pi\left(f,f\right) & = & 0.11 & > & E\Pi\left(i,f\right) & = & 0.00 \\
 & E\Pi\left(f,i\right) & = & 0.82 & < & E\Pi\left(i,i\right) & = & 2.94
\end{array}$$

Example 3: $\mu = 0.1$, $\alpha_1 = 4$, $\alpha_2 = 15$, $x = 5$, $\beta = 1$, $c = 0.2$, $K = 4$, $H = 0.5$ and $B = 6$.

Profit levels:

$$\begin{array}{lccccccc}
4 \leq A_h & E\Pi(f,f) & = & 17.56 & < & E\Pi(i,f) & = & 18.05 \\
 & E\Pi(f,i) & = & 17.47 & < & E\Pi(i,i) & = & 17.60 \\
 & & & & & & & \\
2.9 \leq A_h < 4 & E\Pi(f,f) & = & 17.56 & > & E\Pi(i,f) & = & 17.45 \\
 & E\Pi(f,i) & = & 17.47 & > & E\Pi(i,i) & = & 17.00 \\
 & & & & & & & \\
0.89 \leq A_h < 2.9 & E\Pi(f,f) & = & 16.96 & < & E\Pi(i,f) & = & 17.45 \\
 & E\Pi(f,i) & = & 17.47 & > & E\Pi(i,i) & = & 17.00 \\
 & & & & & & & \\
A_h < 0.89 & E\Pi(f,f) & = & 16.96 & < & E\Pi(i,f) & = & 17.45 \\
 & E\Pi(f,i) & = & 16.87 & < & E\Pi(i,i) & = & 17.00
\end{array}$$

Example 4: $\mu = 0.5$, $\alpha_1 = 5$, $\alpha_2 = 10$, $x = 4$, $\beta = 1$, $c = 0.2$, $K = 2.5$, $H = 0.1$ and $B = 3$.

Profit levels:

$$\begin{array}{lccccccc}
2.5 \leq A_h & E\Pi(f,f) & = & 4.02 & < & E\Pi(i,f) & = & 4.10 \\
 & E\Pi(f,i) & = & 1.69 & < & E\Pi(i,i) & = & 1.90 \\
 & & & & & & & \\
2.44 \leq A_h < 2.5 & E\Pi(f,f) & = & 4.02 & < & E\Pi(i,f) & = & 4.10 \\
 & E\Pi(f,i) & = & 1.69 & > & E\Pi(i,i) & = & 1.15 \\
 & & & & & & & \\
0.9 \leq A_h < 2.44 & E\Pi(f,f) & = & 4.02 & < & E\Pi(i,f) & = & 4.10 \\
 & E\Pi(f,i) & = & 0.19 & < & E\Pi(i,i) & = & 1.15 \\
 & & & & & & & \\
0.04 \leq A_h < 0.9 & E\Pi(f,f) & = & 4.02 & > & E\Pi(i,f) & = & 2.60 \\
 & E\Pi(f,i) & = & 0.82 & < & E\Pi(i,i) & = & 1.15 \\
 & & & & & & & \\
A_h < 0.04 & E\Pi(f,f) & = & 2.51 & < & E\Pi(i,f) & = & 2.60 \\
 & E\Pi(f,i) & = & 0.82 & < & E\Pi(i,i) & = & 1.15
\end{array}$$

Example 5: $\mu = 0.3$, $\alpha_1 = 5$, $\alpha_2 = 18$, $x = 6$, $\beta = 1$, $c = 0.2$, $K = 4$, $H = 0.75$ and $B = 3$.

Profit levels:

$$\begin{array}{lccccccc}
4 \leq A_h & E\Pi(f,f) & = & 20.66 & < & E\Pi(i,f) & = & 20.78 \\
 & E\Pi(f,i) & = & 21.35 & > & E\Pi(i,i) & = & 20.36 \\
 & & & & & & & \\
2.19 \leq A_h < 4 & E\Pi(f,f) & = & 20.66 & > & E\Pi(i,f) & = & 19.88 \\
 & E\Pi(f,i) & = & 21.35 & > & E\Pi(i,i) & = & 19.46 \\
 & & & & & & & \\
A_h < 2.19 & E\Pi(f,f) & = & 19.76 & < & E\Pi(i,f) & = & 19.88 \\
 & E\Pi(f,i) & = & 21.35 & > & E\Pi(i,i) & = & 19.46
\end{array}$$

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FIGURE $1'$

Equilibrium technological configurations in example 1, $\omega \in \Omega_1$**:**
in Y, either (f,f) **or** (i,i)**; in V,** (f,i) **or** (i,f)**;**
in W, no equilibrium in pure strategies.

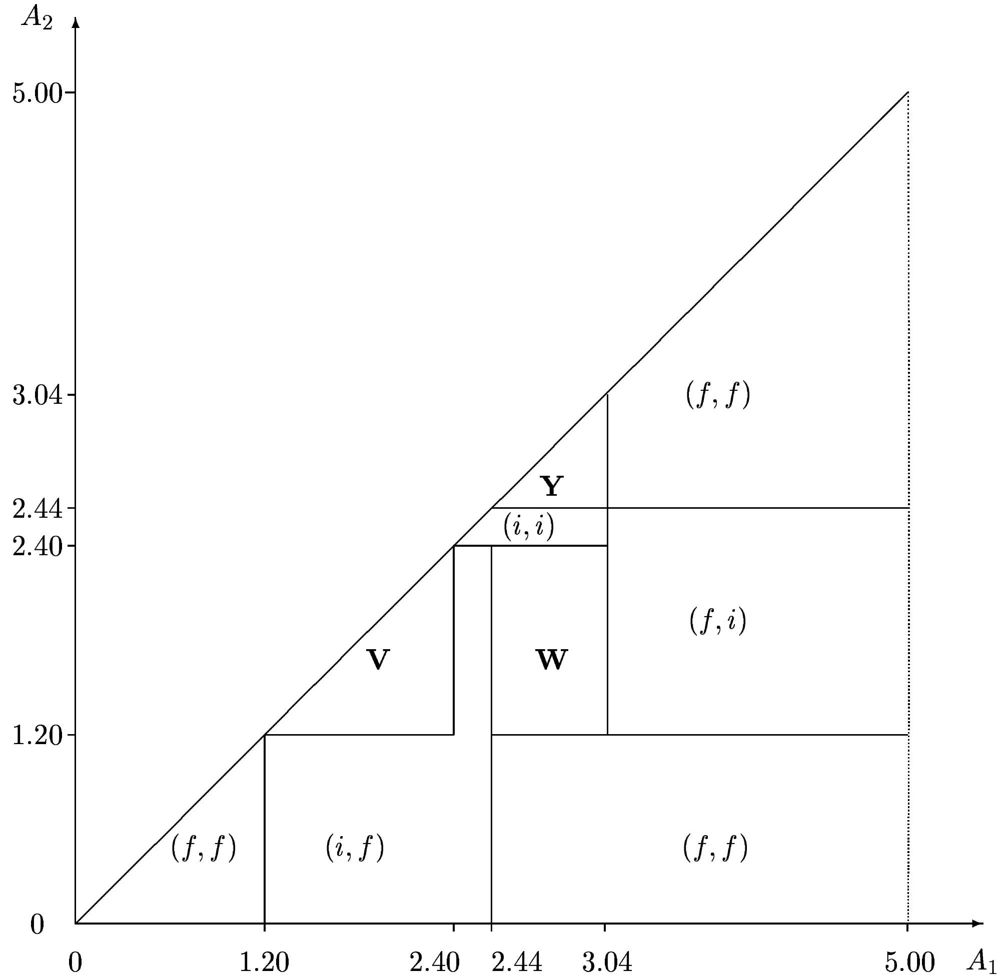

FIGURE 2′

Equilibrium technological configurations in example 2, $\omega \in \Omega_2$**:**

in Y, either (f, f) **or** (i, i)**.**

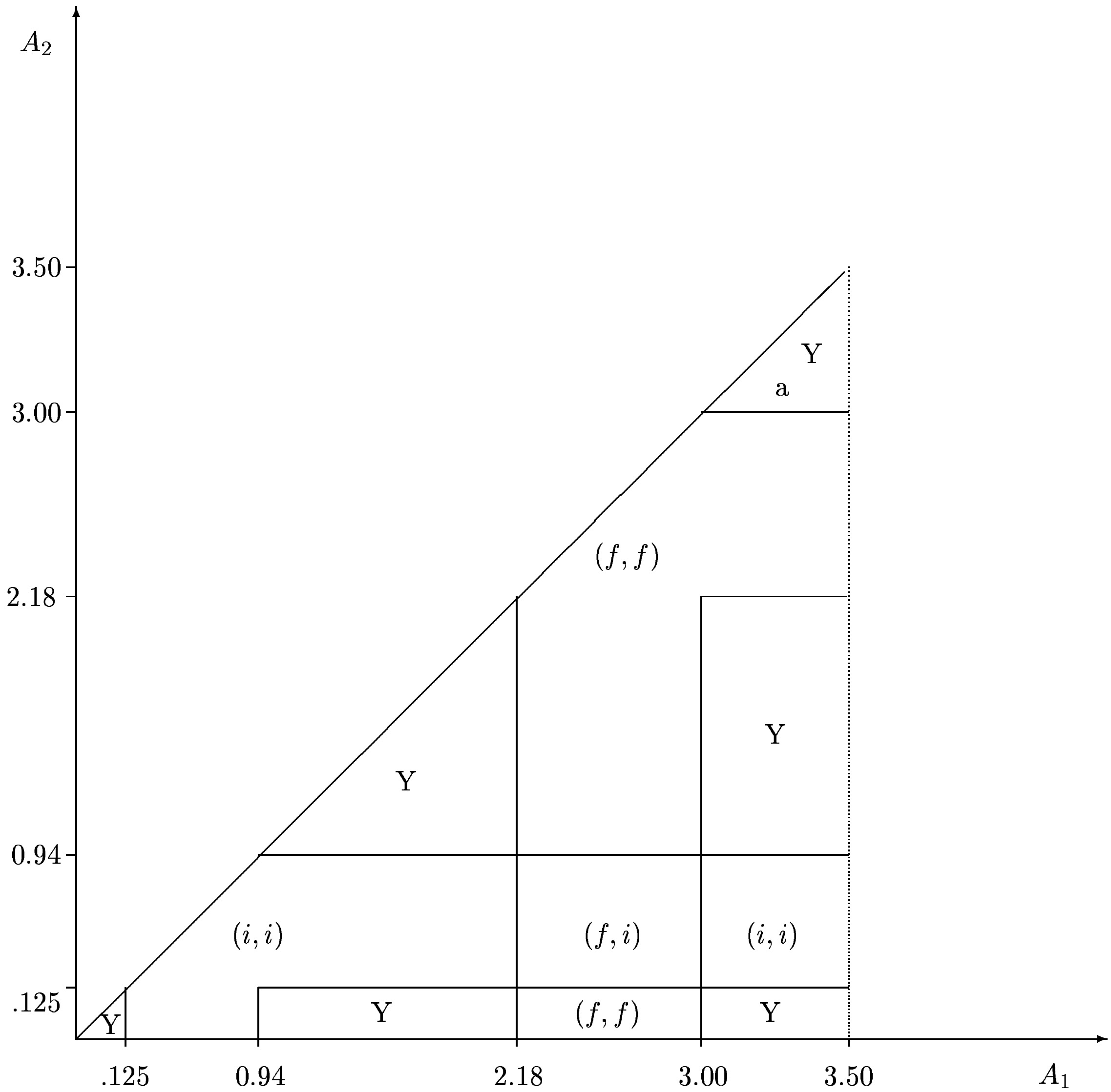

FIGURE $3'$

Equilibrium technological configurations in example 3, $\omega \in \Omega_3$**:**

in V, (f,i) **or** (i,f)**.**

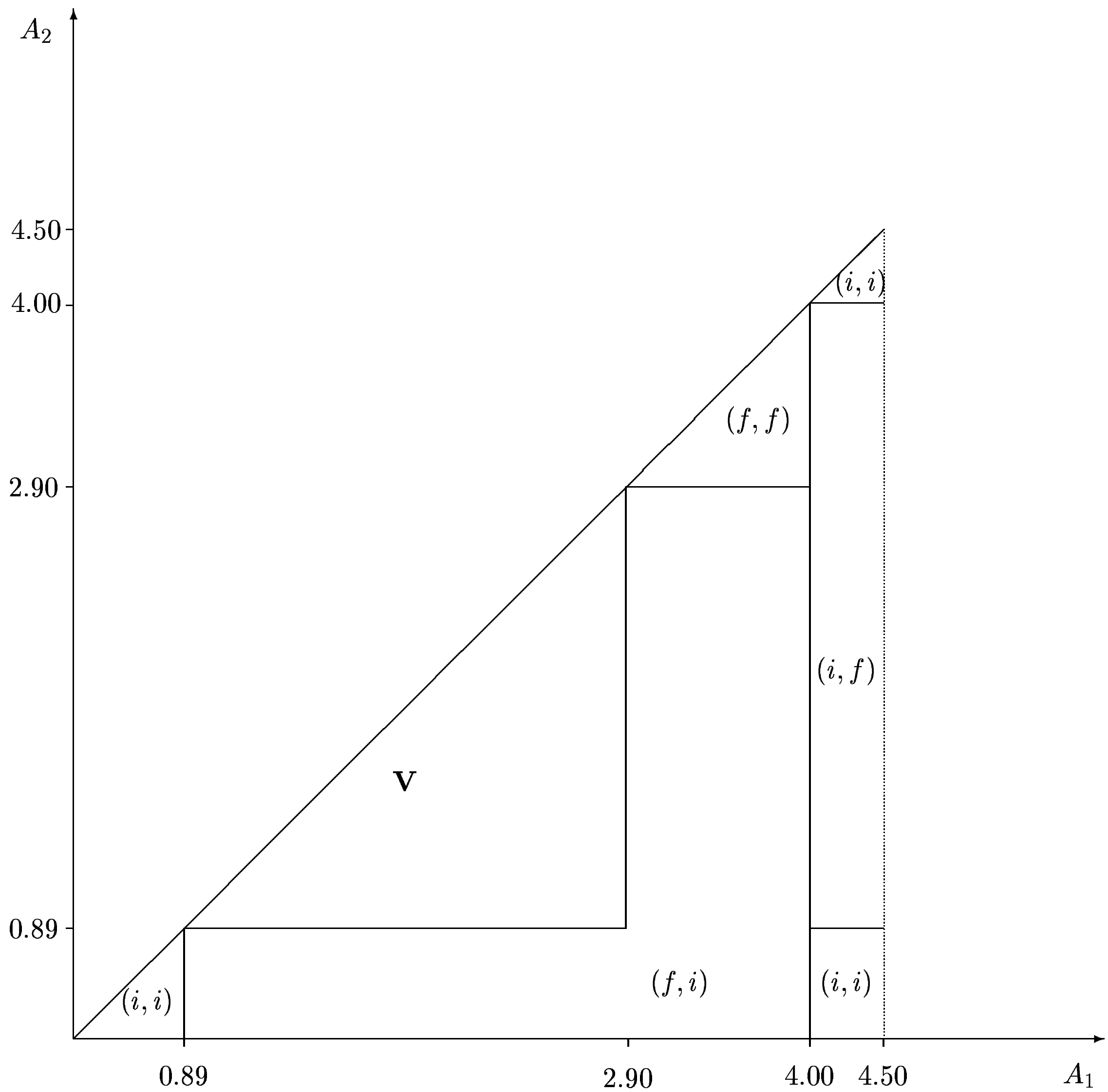

FIGURE 4

Equilibrium technological configurations in example 4, $\omega \in \Omega_2$: in Y, (f,f) or (i,i); in S, (f,i); in V, (f,i) or (i,f); in W, no equilibrium in pure strategies.

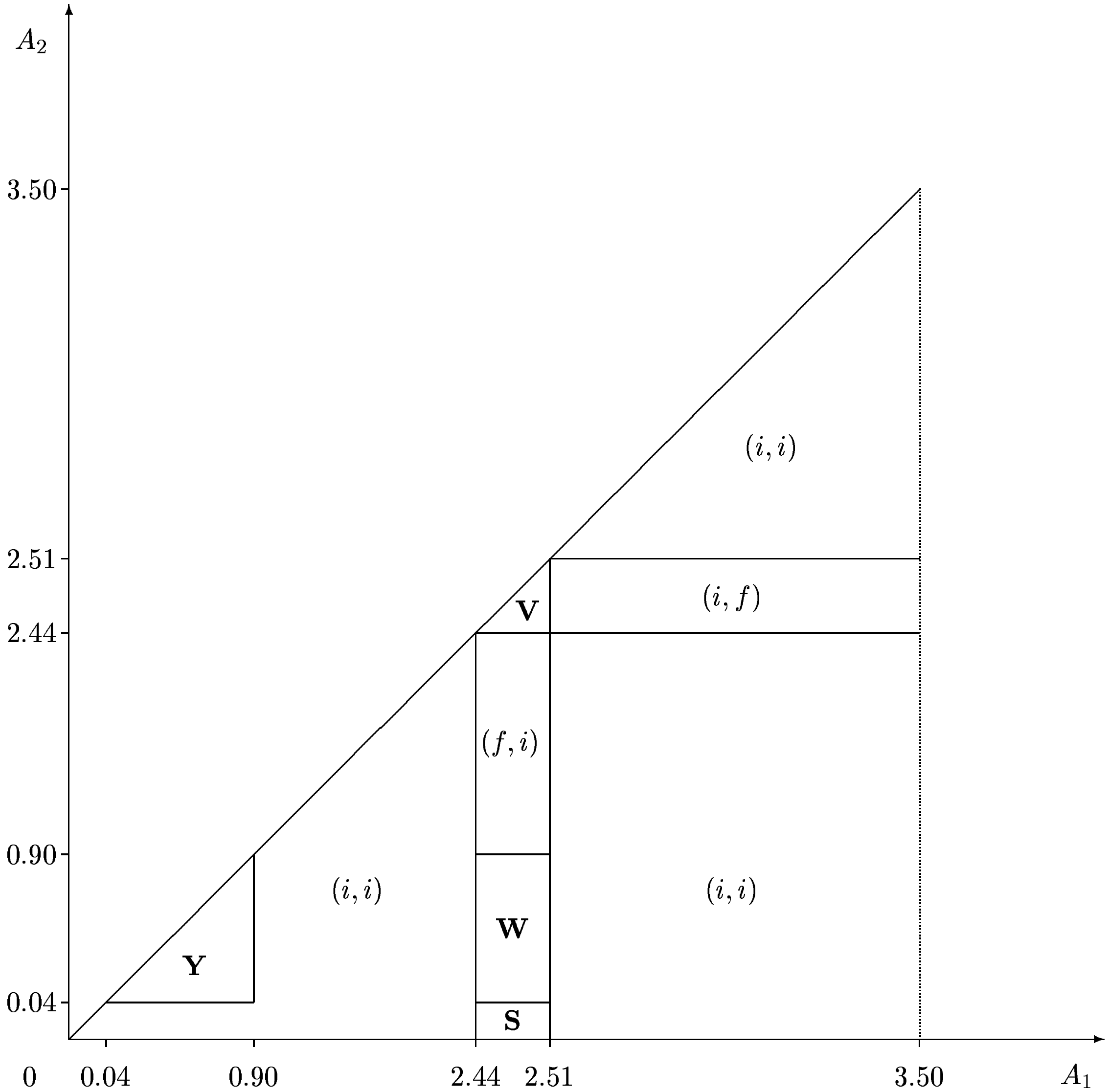

FIGURE 5

Equilibrium technological configurations in example 5, $\omega \in \Omega_3$: in V, (f,i) or (i,f).