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EXTERNAL FINANCING AND STRATEGIC TECHNOLOGICAL CHOICES*

by

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Abstract

We study the interactions between debt/equity financing and strategic (duopoly) technological flexibility choices of firms facing 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, either a less costly inflexible technology or a more expensive flexible technology. The level of financial hardship has a non-monotonic effect: as the level of equity financing increases, the choice of technology may switch and the level of investment may follow a $\bigcap$-shaped or $\bigcup$-shaped path, depending on the differential investment cost, the bankruptcy cost, and whether or not the less costly technology is the best option or not for an all equity firm. We also 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, 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

Bankruptcy costs and capital structure have both significant impacts on the equilibrium technological configurations in some industries. These effects arise because leveraged firms must manage their adaptability to changing market conditions and simultaneously take into account the strategic aspects of their choices when operating in imperfectly competitive markets. This can be done by choosing flexible technologies to reduce the probability of bankruptcy. We show in 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 but a different one for intermediate leverage levels.

In Brander and Lewis (1986), a firm's output level increases with its debt level. More recently, Leach, Moyen and Yang (2003) consider a leader-follower framework in capacity and debt financing levels, with production levels chosen simultaneously. 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.[1] In our model, the link between debt levels and product market competition is somewhat more complex since debt induces not only changes in output and prices given the technologies but also changes in the technologies or production cost functions themselves. We show that more 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 invest in flexible technologies resulting in more volatile industry outputs but less volatile prices. Therefore, the effects characterized by Brander and Lewis (1986), Glazer (1994), and Showalter (1995) among others, depend closely on the implicit assumption that technologies are exogenously given.[2] If firms are allowed to choose between different technologies with different ability to adjust to changing market conditions, the impact of debt financing becomes in general non-monotonic.

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

[1] They empirically test the deterrent role of capacity and debt financing by looking at the telecommunications industry in the U.S. where more competition was 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.

[2] Leach, Moyen and Yang (2003) consider, besides leverage, investment in capacity.

and investment stage. It complements the empirical analysis of Hadlock (1998), Fazzari, Hubbard and Petersen (1988, 2000), Kaplan and Zingales (1997, 2000), Cleary (1999) and Cleary, Povel and Raith (2005). 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 market strategy of firms. We show that for some market and industry parameters, debt or more generally external financing increase a firm's expected profit but for other parameters, external financing is a source of weakness and decreases expected profit. Debt may also change the 'selection' of a technological equilibrium among multiple ones, leading in some cases to a Pareto-dominated equilibrium, in the present case a flexibility trap.

Hadlock (1998) estimated empirically a nonlinear relationship between insider shareholdings and the sensitivity of a firm's investment to its cash flow. Higher insider (management) holdings imply a better alignment between shareholders' interests (outsiders) and managers' interests (insiders). Hadlock's empirical results suggest that as insider holdings increase, investment sensitivities to internal cash flows rise sharply before leveling off and decreasing slowly after a certain point. Hadlock shows that these results are inconsistent with the hypothesis that managers tend to overinvest the internal cash flows but supportive of the alternative hypothesis that asymmetric-information problems between internal and external financing make the latter even more expensive when the managers' interests are more congruent with those of shareholders. This suggests an empirical $\bigcap$-shaped relationship, which is in a sense predicted in our model (Propositions 1 and 4).

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 have disrupted the earlier consensus to the contrary, as reviewed in Hubbard (1998). 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 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 $\bigcap$-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.[3] Hence, if enough firms find themselves in a $\bigcup$-shaped relationship, that is creditworthy firms invest more than financially constrained types because the latter find desirable to trade market opportunities for a lower probability of bankruptcy (Example/Figure 2 below), then our model predicts the empirical results of Kaplan and Zingales (1997) and Cleary (1999). On the other hand, if enough firms find themselves in a $\bigcap$-shaped relationship (Example/Figure 4 below), the prediction is the 'empirical consensus' results surveyed by Hubbard (1998).[4]

More recently Cleary, Povel and Raith (2005) analyze how the availability of internal funds affects a firm's investment in the presence of capital market imperfections and show that under otherwise standard assumptions (more costly external funds may lead to the inefficient liquidation of the firm, the cost of external funds is endogenously determined by the investor's rate of return requirement, investment is scalable), investment is a $\bigcup$-shaped function of internal funds. As internal funds decrease, the cost of maintaining a given investment program increases, which makes a lower investment level more attractive. For low internal funds, however, the firm will be induced to invest more not less: a larger investment generates more revenue, which makes it easier to repay the lender and therefore benefits the firm. They test their theory using a rather comprehensive data set and find strong support for their predictions: a negative [positive] relation between investment and internal funds for a sizable fraction of firms with low [high] levels of internal funds. This suggests a $\bigcup$-shaped relationship similar to a prediction in our model (Propositions 2 and 3).[5]

We like to think that our results are a step in trying to explain those conflicting empirical

[3]Clearly this non monotonicity holds also at the industry level.

[4]See also the subsequent discussions in Fazzari, Hubbard and Petersen (2000) and Kaplan and Zingales (2000).

[5]We make the first two 'standard' assumptions of Cleary, Povel and Raith (2005) but instead of the scalability of investment, we assume different types (flexible or inflexible) of technological investment, which involve different investment levels and may serve to mitigate the risk of bankruptcy.

regularities. We like to think also that our results contribute to a better understanding of the complex interconnections between capital structure, technological flexibility, and product market competition under significant costs of financial distress.

The paper is organized as follows. We present the model and the equilibrium concept in section 2. We derive in section 3 the profit functions of the firms and we characterize the competitive debt contracts for given technologies. In section 4, we characterize the technological best reply functions and we study the impact of equity financing on technological flexibility choices, in particular the non monotonic effect of equity financing through a series of simple but revealing numerical examples. In section 5, we analyze the strategic value of equity, the role of debt as a commitment device, the role of bankruptcy costs, and we characterize the joint determination of capital structure and technological flexibility. We conclude in section 6.

2 The model

We consider an homogeneous product duopoly with firms choosing between two technologies, an inflexible (i) and a flexible (f). An inflexible firm either produces x, where x is the exogenous capacity, or shuts down.[6] 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.

The inverse demand function is assumed to be linear:[7]

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

where Q is the aggregate output and α is a random variable taking lower value α_1 (low demand) with probability μ and higher α_2 (high demand) with probability $1 - \mu$.

[6]We consider x as exogenous to simplify the model. An endogenously chosen x would make the discussion much more complex without much gain in the present context. Indeed, assuming that the inflexible firm produces x or shuts down exacerbates the strategic value (and cost) of inflexibility and commitment, which contributes to make the results sharper without significant loss of generality.

[7]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.

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, for matter of simplicity only, that it is raised through borrowing.[8] 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.[9]

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. In spite of the apparent complexity of such an approach, we will be able to characterize the equilibrium strategies in a rather simple way.

Clearly, debt contracts are not in practice a function of the technological configuration of the industry. This modeling strategy must be understood as representing the "business plan" typically required by banks, which will refer at least implicitly to the type of technology and

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

[9] In the case of external equity financing, the entrepreneur would similarly suffer from a loss of reputation in addition to the dilution of his ownership.

level of capacity installed by other firms in the industry and to the volatility of market conditions and therefore to the firm's profit levels in different states and the risk it represents. Hence the debt contracts and the technologies or flexibility levels are chosen simultaneously within a firm and across firms. In the second stage, the entrepreneurs observe the level of demand 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 interdependencies between corporate finance (internal liquidity, equity and debt financing), firms' technological investments (both the type of investment or flexibility and the level of capital expenditures), significant bankruptcy cost, and demand uncertainty.

3 Expected profits and financial contracts given the technologies

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. We will assume (without loss of generality) that in the high state of demand (α_2), both firms produce and avoid bankruptcy at the Cournot stage of the game whatever their technological choices and that, in the state of low demand, a firm with low equity goes bankrupt whatever its technology.[10] The second stage Cournot equilibrium profits over operating costs, as functions of the technological choices of the firms, are derived in Appendix A.

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 Ω_s:

- $\Omega_1 \equiv \{\omega \mid x < (\alpha_1 - c)/2\beta\} \equiv \{\omega \mid \alpha_1 > 2\beta x + c\}$: The capacity x of the inflexible technology is small relative to the size of the market under low demand α_1, implying that

[10] In other words, the level of profit over variable cost, which a firm realizes in the low state of demand, is always less that the cost, K or $K + H$, of the technologies. These simplifying assumptions allow us to concentrate on the more interesting cases.

even under low demand, both firms produce at the second stage of the game whatever their 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 α_1 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 α_1 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 of the industry technological configurations and the parameter set Ω. The debt threshold, over which the firm goes bankrupt, is simply the profit level $\pi_1(t, t', \Omega)$.

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 $\pi_1(f, t', \Omega)$. 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 return normalized at 0), the repayment R_h is then simply equal to the amount borrowed $K + H - A_h$. On the other hand, if D 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 $\pi_1(f, t', \Omega)$ as the bank seizes the firm's assets. Hence, 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:

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

We see from (1) that the financial contract negotiated between firm h and a bank is a function of the technologies chosen by both firms and of the equity of firm h: the cost of external finance is endogenous.

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 $(1-\mu)\left[\pi_2(f, t', \Omega) - R_h\right] - \mu B - A_h$ where R_h is now given by (1). Thus, we obtain the expected profit of a flexible firm facing a competitor with technology $t' \in \{i, f\}$:

$$E\Pi(f,\ t',\ \Omega) = \begin{cases} \widehat{E\Pi}\,(f, t', \Omega)\,, & \text{if } K + H - A_h \leq \pi_1(f, t', \Omega) \\ \widehat{E\Pi}\,(f, t', \Omega) - \mu B, & \text{if } K + H - A_h > \pi_1(f, t', \Omega) \end{cases} \tag{2}$$

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

$$\widehat{E\Pi}\,(f, t', \Omega) = \left[\mu\pi_1(f, t', \Omega) + (1-\mu)\, \pi_2(f, t', \Omega)\right] - (K + H)\,. \tag{3}$$

The difference between the two profit levels in (2) is the expected bankruptcy cost. The expressions for $\pi_k(\cdot)$ and $\widehat{E\Pi}(\cdot)$ 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 $\omega \in \Omega_{13} \equiv \Omega_1 \cup \Omega_3$ 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: if its debt level $D = K - A_h$ is smaller than this profit level, it avoids bankruptcy and its repayment is simply $K - A_h$; 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:

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

The firm's expected profit is therefore given by (where Ω may be Ω_{13} or Ω_2)

$$E\Pi\left(i,t',\Omega\right)=\begin{cases}\widehat{E\Pi}\left(i,t',\Omega\right), & \text{if } K-A_h\leq\pi_1(i,t',\Omega)\\ \widehat{E\Pi}\left(i,t',\Omega\right)-\mu B, & \text{if } K-A_h>\pi_1(i,t',\Omega)\end{cases}\tag{5}$$

where

$$\widehat{E\Pi}\left(i,t',\Omega\right)=\mu\pi_1(i,t',\Omega)+\left(1-\mu\right)\pi_2(i,t',\Omega)-K.\tag{6}$$

In the latter case, $\omega\in\Omega_2$ and $t'=i$, only one firm produces when demand is low. We assume that the producing firm is determined randomly with equal probability.[11] 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 $D=K-A_h>\pi_1(i,i,X_2)$. The repayment R_h to be paid in the good state of demand is then given by

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

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

$$E\Pi\left(i,i,\Omega_2\right)=\begin{cases}\widehat{E\Pi}\left(i,i,\Omega_2\right), & \text{if } K-A_h\leq 0\\ \widehat{E\Pi}\left(i,i,\Omega_2\right)-\frac{1}{2}\mu B, & \text{if } 0<K-A_h\leq\pi_1(i,i,\Omega_2)\\ \widehat{E\Pi}\left(i,i,\Omega_2\right)-\mu B, & \text{if } \pi_1(i,i,\Omega_2)<K-A_h\end{cases}\tag{8}$$

where

$$\widehat{E\Pi}\left(i,i,\Omega_2\right)=\mu\frac{1}{2}\pi_1(i,i,\Omega_2)+\left(1-\mu\right)\pi_2(i,i,\Omega_2)-K.\tag{9}$$

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 equity financing or internal liquidity on the technological equilibrium of the industry, we must first determine its impact on the technological best reply functions.

[11] This is the natural equilibrium to choose here and it could be justified in a rigorous way as a markov perfect equilibrium in a continuous time game model using entry/exit strategies defined as intensity functions, under which firms can avoid symmetrically the "mistake" of being both in the market. See Boyer, Lasserre, Mariotti, and Moreaux (2004) for an example of such an analysis.

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 (exogenous) equity or 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. If there is no cost of financial distress (bankruptcy), 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.[12] 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.[13]

Hence, two elements are crucial in this analysis, first the level of bankruptcy cost B and second the firm's borrowing needs, which will depend on both its capital expenditures, its technology, and its equity or liquidity level A. Large values of B induce firms to opt for more flexibility and reduced borrowing in order to avoid costly bankruptcy. 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 probability of bankruptcy.

The critical levels of B and H will depend on ω, that is on the capacity of the inflexible technology relative to the size of the market under low demand since bankruptcy occurs only in the low demand state (see Appendix B).

- $\Omega \in \{\Omega_1,\ \Omega_3\}$: H is considered large if it is larger than the profit differential $\pi_1(f,i,\Omega)-\pi_1(i,i,\Omega)$ under low demand; B is considered large if μB is larger than the absolute value $|\widehat{E\Pi}(i,i,\Omega)-\widehat{E\Pi}(f,i,\Omega)|$ of the profit differential for an all equity firm.
- $\Omega=\Omega_2$: H is large if it is larger than the profit level $\pi_1(f,i,\Omega_2)$, small if 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 μB 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 μB is larger than twice that value.

With these benchmarks in mind, we can characterize the best response to inflexibility and

[12]The result can be obtained directly from expressions (12) to (16) in Appendix B.
[13]The firm self-insures against bankruptcy by switching between technologies.

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 large in the above sense.

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 $E\Pi(i, i, \Omega) - E\Pi(f, i, \Omega)$, 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 its technology.[14] 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 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; otherwise, inflexibility is the best response for low and high levels of equity while flexibility 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 is larger for intermediate levels: the relation between the level of investment and the level of equity finanicng or internal liquidity is therefore non-monotonic ($\bigcap$-shaped relation).*

[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.

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 H is small; otherwise, flexibility is the best response for low and high levels of equity financing while 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 is smaller for intermediate levels: the relation between the level of investment and the level of equity or internal liquidity is therefore non-monotonic ($\bigcup$-shaped relation).*

When inflexibility is the best response to inflexibility for an all equity firm, that is $\widehat{E\Pi}(i,i,\Omega) \leq \widehat{E\Pi}(f,i,\Omega)$, 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,[15] 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 to give 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.[16] 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,[17] the firm, facing a large differential investment cost H, will prefer to give 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.

[15]The precise bounds are given in Appendix B.

[16]As shown by (13), (15) and (16), the interval for which the level of equity financing is considered 'intermediate' depends on the case considered.

[17]This case is not explicitly developed here but it follows steps similar to those in Appendix B with reversed inequalities.

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:

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

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 financing if H is small; otherwise, flexibility is the best response for low and high levels of equity financing while inflexibility becomes the best response for intermediate levels: the relation between the level of capital expenditures and equity financing or internal liquidity is non-monotonic ($\bigcup$-shaped relation).*

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 financing if H is large; otherwise, inflexibility is the best response for low and high levels of equity financing while flexibility becomes the best response for intermediate levels: the relation between the level of capital expenditures and equity financing or internal liquidity is non-monotonic ($\bigcap$-shaped relation).*

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 when 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

From our characterization of technological best reply functions, it is straightforward to obtain the technological equilibrium in the different cases. As mentioned in the introduction, the main result of the present paper is to show the existence of a *non monotonic* relation between investment and equity financing levels: as the level of equity financing increases, a *reswitching of technologies* phenomenon occurs in some context, depending on the cost of financial distress and the differential cost of technologies.

Rather than proceed with a complete characterization of equilibrium technological configurations, it will suffice for our purpose to illustrate the existence of the non monotonicity (reswitching of technologies) result in different contexts. We present in this section numerical examples which will prove sufficient to illustrate how equilibrium technological configurations in the industry emerge from debt or equity financing levels. The examples are worked out in detail in Appendix C. In the first three examples, we use the same parameter values, except for α_1, in order to illustrate the impact of moving from Ω_1 to Ω_2 to Ω_3:

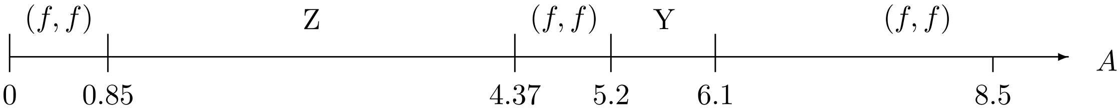
$$\mu = 0.5,\ \alpha_2 = 15,\ x = 3,\ \beta = 1,\ c = 0.2,\ K = 5.5,\ H = 3,\ B = 6.$$

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 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.[18] 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.[19] One can also observe that the technological choice (and capital expenditures) of a firm may be a 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 (α_1) relative to the capacity of

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

[19] 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).

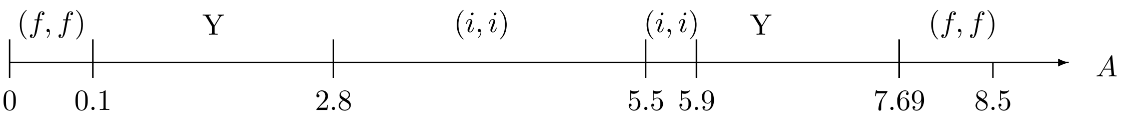
the inflexible technology (x).

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.[20] 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.[21] Below 2.8, adopting inflexibility decreases the risk of bankruptcy (without eliminating it) only if

[20]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.

[21]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 μ to $\mu/2$. The unique equilibrium remains (i, i).

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 $A < 5.5$).

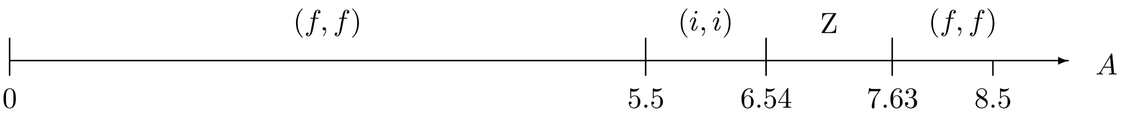
Example 3: $\alpha_1 = 3$ **(**$\omega \in \Omega_3$**)**

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, $\omega \in \Omega_3$:

[in Z, (i, f) or (f, 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: **(**$\omega \in \Omega_3$**)**

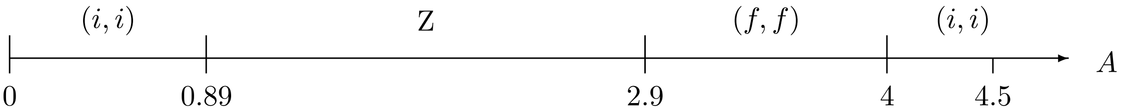
$$\mu = 0.1,\ \alpha_1 = 4,\ \alpha_2 = 15,\ x = 5,\ \beta = 1, c = 0.2,\ K = 4,\ H = 0.5,\ B = 6.$$

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 ($A < 2.9$), 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 industry commitment index, a function of both the level of equity financing and the bankruptcy cost.[22]

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 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

[22]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."

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.[23] Another way to increase the bankruptcy costs is to delegate the investment decision to a manager to be fired in case of

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

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.[24]

6 Conclusion

Mackay and Phillips (2005) wrote: "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." We have considered in this paper the relationship between corporate finance and technological choices made by firms, that is, between the firm capital structure, the type of technology chosen, the level of capital expenditures, and the relative performance of the firms in product markets, under significant costs of financial distress

[24]We 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,
And say there is much kindness in the Jew."

or bankruptcy. Most contributions on the joint determination of real and financial decisions.[25] have assumed a given technology, more precisely a given production cost function for the firm. But as forcefully emphasized by Stigler (1939), firms have some degrees of freedom in choosing their cost functions. This introduces new profitability trade-offs. A firm choosing a relatively inflexible technology can reduce the market share of its rival in states of low demand but cannot fully exploit the states of high demand. If the capacity associated with the inflexible technology is large, the firm can reduce the market share of its rival in states of high demand but runs the risk of going bankrupt in the states of low demand.

The need of debt or external financing may 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 affect the probability of bankruptcy, financial and technological choices of a firm are interdependent and must be simultaneously determined. With bankruptcy costs, debt improves the strategic position of the firm in some contexts but is a source of weakness in others. Thus, the relationship between external financing and technological choices is a complex one.

Most business commentators argue that technological flexibility is becoming increasingly valuable as developments in globalization and information and communications technologies have made the markets significantly more volatile. We have shown here, in a model of volume flexibility, that this need not be the case in a strategic context.

[25] Dammon and Senbet (1988), Leland (1998), Bolton and Scharfstein (1990), Chevalier (1995), Phillips (1995), Kovenock and Phillips (1995), Povel and Raith (2004); Brander and Lewis (1986 and 1988), Maksimovic and Zechner (1991), Williams (1995), Fries, Miller and Perraudin (1997); Hubbard (1998), Kaplan and Zingales (1997 and 2000), Cleary (1999), Fazzari, Hubbard and Petersen (2000), Hadlock (1998), Cleary, Povel and Raith (2005); Froot, Scharfstein and Stein (1993), Ammon (1998), Copeland and Copeland (1999), Bartram (2000), Morellec and Smith (2001), MacMinn (2002), Boyer, Boyer and Garcia (2007).

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
  $\widehat{E\Pi}(f,f,\Omega_1) = \dfrac{1}{9\beta}\left[\mu\left(\alpha_1 - c\right)^2 + \left(1-\mu\right)\left(\alpha_2 - c\right)^2\right] - (K+H)$
- 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
  $\widehat{E\Pi}(f,i,\Omega_1) = \dfrac{1}{4\beta}\left[\mu\left(\alpha_1 - c - \beta x\right)^2 + \left(1-\mu\right)\left(\alpha_2 - c - \beta x\right)^2\right] - (K+H)$,
  $\widehat{E\Pi}(i,f,\Omega_1) = \dfrac{1}{2}\left[\mu\alpha_1 + \left(1-\mu\right)\alpha_2 - c - \beta x\right]x - K$
- 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
  $\widehat{E\Pi}(i,i,\Omega_1) = \left[\mu\alpha_1 + \left(1-\mu\right)\alpha_2 - c - 2\beta x\right]x - K$

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

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.

$$\begin{aligned} A(i,i,\Omega) &= K - \pi_1(i,i,\Omega) > 0 \\ A(f,i,\Omega) &= K + H - \pi_1(f,i,\Omega) > 0 \end{aligned} \tag{11}$$

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

<u>Best reply to inflexibility for $\omega \in \Omega_1 \cup \Omega_3$</u>.

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:

$$\begin{aligned}
\widehat{E\Pi}(i,i,\Omega) - \mu B &\geq \widehat{E\Pi}(f,i,\Omega) - \mu B, && \text{for } A_h < A(i,i,\Omega) \\
\widehat{E\Pi}(i,i,\Omega) &\geq \widehat{E\Pi}(f,i,\Omega) - \mu B, && \text{for } A(i,i,\Omega) < A_h < A(f,i,\Omega) \\
\widehat{E\Pi}(i,i,\Omega) &\geq \widehat{E\Pi}(f,i,\Omega), && \text{for } A(f,i,\Omega) < A_h
\end{aligned} \tag{12}$$

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

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

<u>Best reply to inflexibility for $\omega \in \Omega_2$</u>

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:

$$\begin{aligned}
\widehat{E\Pi}(i,i,\Omega_2) - \mu B &> \widehat{E\Pi}(f,i,\Omega_2) - \mu B, && \text{for } A_h < A(i,i,\Omega_2) \\
\widehat{E\Pi}(i,i,\Omega_2) - \tfrac{1}{2}\mu B &> \widehat{E\Pi}(f,i,\Omega_2) - \mu B, && \text{for } A(i,i,\Omega_2) < A_h < K \\
\widehat{E\Pi}(i,i,\Omega_2) &> \widehat{E\Pi}(f,i,\Omega_2) - \mu B, && \text{for } K < A_h < A(f,i,\Omega_2) \\
\widehat{E\Pi}(i,i,\Omega_2) &> \widehat{E\Pi}(f,i,\Omega_2), && \text{for } A(f,i,\Omega_2) < A_h
\end{aligned} \tag{14}$$

- 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

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

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

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

Best reply to flexibility

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

$$\begin{aligned}
A(i,f,\Omega) &= K - \pi_1(i,f,\Omega) > 0 \\
A(f,f,\Omega) &= K + H - \pi_1(f,f,\Omega) > 0
\end{aligned} \tag{17}$$

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

$$\begin{aligned}
\widehat{E\Pi}(i,f,\Omega) - \mu B &\geq \widehat{E\Pi}(f,f,\Omega) - \mu B, && \text{for } A_h < A(i,f,\Omega) \\
\widehat{E\Pi}(i,f,\Omega) &\geq \widehat{E\Pi}(f,f,\Omega) - \mu B, && \text{for } A(i,f,\Omega) < A_h < A(f,f,\Omega) \\
\widehat{E\Pi}(i,f,\Omega) &\geq \widehat{E\Pi}(f,f,\Omega), && \text{for } A(f,f,\Omega) < A_h
\end{aligned} \tag{18}$$

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

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

C Examples used in the text

Example 1 (Ω_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:

$$\begin{array}{rclrcl} A(f,f,\Omega_1) & = & 4.37, & A(i,f,\Omega_1) & = & 0.85 \\ A(f,i,\Omega_1) & = & 6.10, & A(i,i,\Omega_1) & = & 5.20 \end{array}$$

Profits when demand is low:

$$\begin{array}{rclrcl} \pi_1(f,f,\Omega_1) & = & 4.13, & \pi_1(i,f,\Omega_1) & = & 4.65 \\ \pi_1(f,i,\Omega_1) & = & 2.40, & \pi_1(i,i,\Omega_1) & = & 0.30 \end{array}$$

Profit levels:

$$\begin{array}{crclcrcl} 6.1 \leq A_h & E\Pi\,(f,f) & = & 5.74 & > & E\Pi\,(i,f) & = & 5.68 \\ & E\Pi\,(f,i) & = & 10.11 & > & E\Pi\,(i,i) & = & 7.85 \\ & & & & & & & \\ 5.2 \leq A_h < 6.1 & E\Pi\,(f,f) & = & 5.74 & > & E\Pi\,(i,f) & = & 5.68 \\ & E\Pi\,(f,i) & = & 7.11 & < & E\Pi\,(i,i) & = & 7.85 \\ & & & & & & & \\ 4.37 \leq A_h < 5.2 & E\Pi\,(f,f) & = & 5.74 & > & E\Pi\,(i,f) & = & 5.68 \\ & E\Pi\,(f,i) & = & 7.11 & > & E\Pi\,(i,i) & = & 4.85 \\ & & & & & & & \\ 0.85 < A_h < 4.37 & E\Pi\,(f,f) & = & 2.74 & < & E\Pi\,(i,f) & = & 5.68 \\ & E\Pi\,(f,i) & = & 7.11 & > & E\Pi\,(i,i) & = & 4.85 \\ & & & & & & & \\ A_h < 0.85 & E\Pi\,(f,f) & = & 2.74 & > & E\Pi\,(i,f) & = & 2.68 \\ & E\Pi\,(f,i) & = & 7.11 & > & E\Pi\,(i,i) & = & 4.85 \end{array}$$

Example 2 (Ω_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:

$$\begin{array}{lclllcl} A(f,f,\Omega_2) & = & 5.94, & A(i,f,\Omega_2) & = & 2.80 \\ A(f,i,\Omega_2) & = & 7.69, & A(i,i,\Omega_2) & = & 5.50 \text{ and } 0 \end{array}$$

Profits when demand is low:

$$\begin{array}{lcllcl} \pi_1(f,f,\Omega_2) & = & 2.56, & \pi_1(i,f,\Omega_2) & = & 2.70 \\ \pi_1(f,i,\Omega_2) & = & 0.81, & \pi_1(i,i,\Omega_2) & = & \begin{cases} 0 & \text{with probability } 1/2 \\ 5.4 & \text{with probability } 1/2 \end{cases} \end{array}$$

Profit levels:

$$\begin{array}{clclclcr} 7.69 \leq A_h & E\Pi\,(f,f) & = & 4.95 & > & E\Pi\,(i,f) & = & 4.7 \\ & E\Pi\,(f,i) & = & 9.31 & > & E\Pi\,(i,i) & = & 9.05 \\ \\ 5.94 \leq A_h < 7.69 & E\Pi\,(f,f) & = & 4.95 & > & E\Pi\,(i,f) & = & 4.7 \\ & E\Pi\,(f,i) & = & 6.31 & < & E\Pi\,(i,i) & = & 9.05 \\ \\ 5.5 \leq A_h < 5.94 & E\Pi\,(f,f) & = & 1.95 & < & E\Pi\,(i,f) & = & 4.7 \\ & E\Pi\,(f,i) & = & 6.31 & < & E\Pi\,(i,i) & = & 9.05 \\ \\ 2.8 \leq A_h < 5.5 & E\Pi\,(f,f) & = & 1.95 & < & E\Pi\,(i,f) & = & 4.7 \\ & E\Pi\,(f,i) & = & 6.31 & < & E\Pi\,(i,i) & = & 7.55 \\ \\ 0.1 \leq A_h < 2.8 & E\Pi\,(f,f) & = & 1.95 & > & E\Pi\,(i,f) & = & 1.7 \\ & E\Pi\,(f,i) & = & 6.31 & < & E\Pi\,(i,i) & = & 7.55 \\ \\ A_h < 0.1 & E\Pi\,(f,f) & = & 1.95 & > & E\Pi\,(i,f) & = & 1.7 \\ & E\Pi\,(f,i) & = & 6.31 & > & E\Pi\,(i,i) & = & 6.05 \end{array}$$

Example 3 (Ω_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:

$$\begin{array}{rclrcl} A(f,f,\Omega_3) & = & 7.63, & A(i,f,\Omega_3) & = & 5.50 \\ A(f,i,\Omega_3) & = & 6.54, & A(i,i,\Omega_3) & = & 5.50 \end{array}$$

Profits when demand is low:

$$\begin{array}{rclrcl} \pi_1(f,f,\Omega_3) & = & 0.87, & \pi_1(i,f,\Omega_3) & = & 0 \\ \pi_1(f,i,\Omega_3) & = & 1.96, & \pi_1(i,i,\Omega_3) & = & 0 \end{array}$$

Profit levels:

$$\begin{array}{crcrcrcr} 7.63 \leq A_h & E\Pi\,(f,f) & = & 4.1 & > & E\Pi\,(i,f) & = & 3.35 \\ & E\Pi\,(f,i) & = & 9.89 & > & E\Pi\,(i,i) & = & 7.7 \\ \\ 6.54 \leq A_h < 7.63 & E\Pi\,(f,f) & = & 1.1 & < & E\Pi\,(i,f) & = & 3.35 \\ & E\Pi\,(f,i) & = & 9.89 & > & E\Pi\,(i,i) & = & 7.7 \\ \\ 5.5 \leq A_h < 6.54 & E\Pi\,(f,f) & = & 1.1 & < & E\Pi\,(i,f) & = & 3.35 \\ & E\Pi\,(f,i) & = & 6.89 & < & E\Pi\,(i,i) & = & 7.7 \\ \\ A_h < 5.5 & E\Pi\,(f,f) & = & 1.1 & > & E\Pi\,(i,f) & = & 0.35 \\ & E\Pi\,(f,i) & = & 6.89 & > & E\Pi\,(i,i) & = & 4.7 \end{array}$$

Example 4 (Ω_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:

$$\begin{array}{rclrcl} A(f,f,\Omega_3) & = & 2.90, & A(i,f,\Omega_3) & = & 4.00 \\ A(f,i,\Omega_3) & = & 0.89, & A(i,i,\Omega_3) & = & 4.00 \end{array}$$

Profits when demand is low:

$$\begin{array}{rclrcl} \pi_1(f,f,\Omega_3) & = & 1.60, & \pi_1(i,f,\Omega_3) & = & 0 \\ \pi_1(f,i,\Omega_3) & = & 3.61, & \pi_1(i,i,\Omega_3) & = & 0 \end{array}$$

Profit levels:

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

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FIGURE $1'$

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.

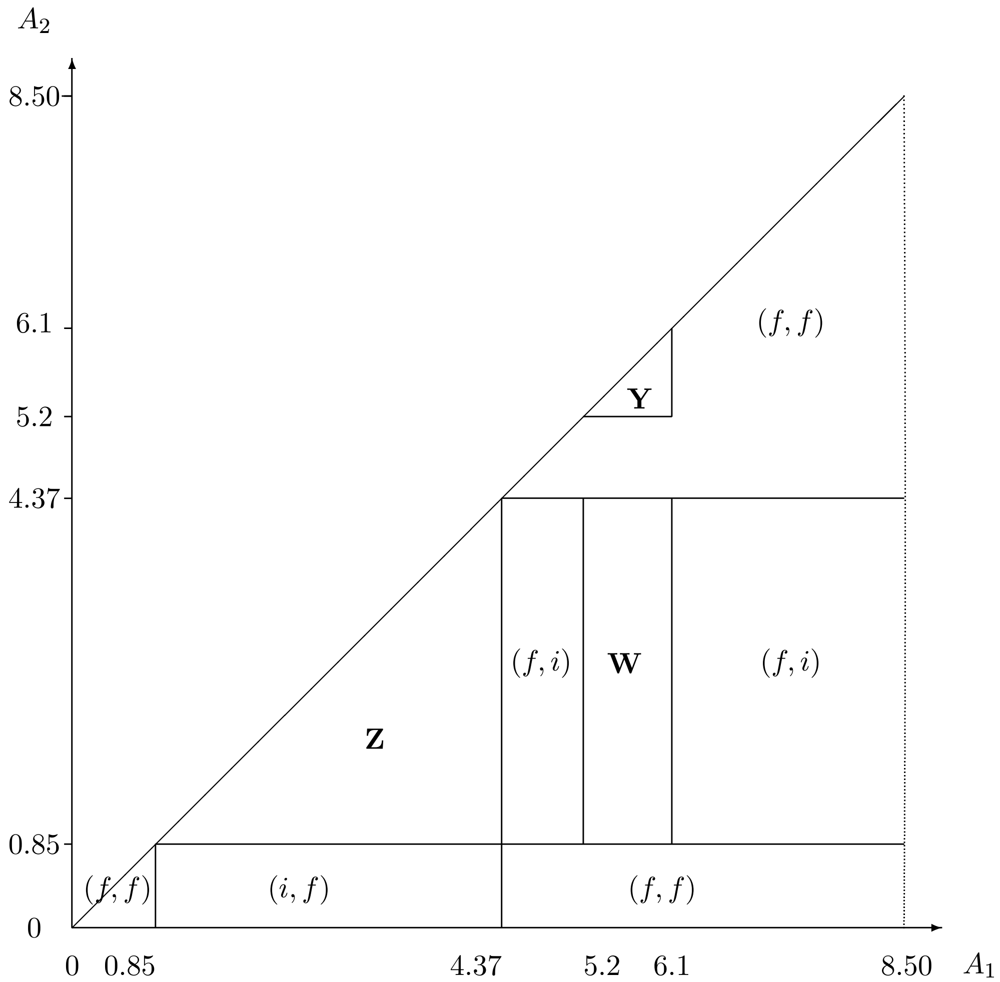

FIGURE $2'$

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

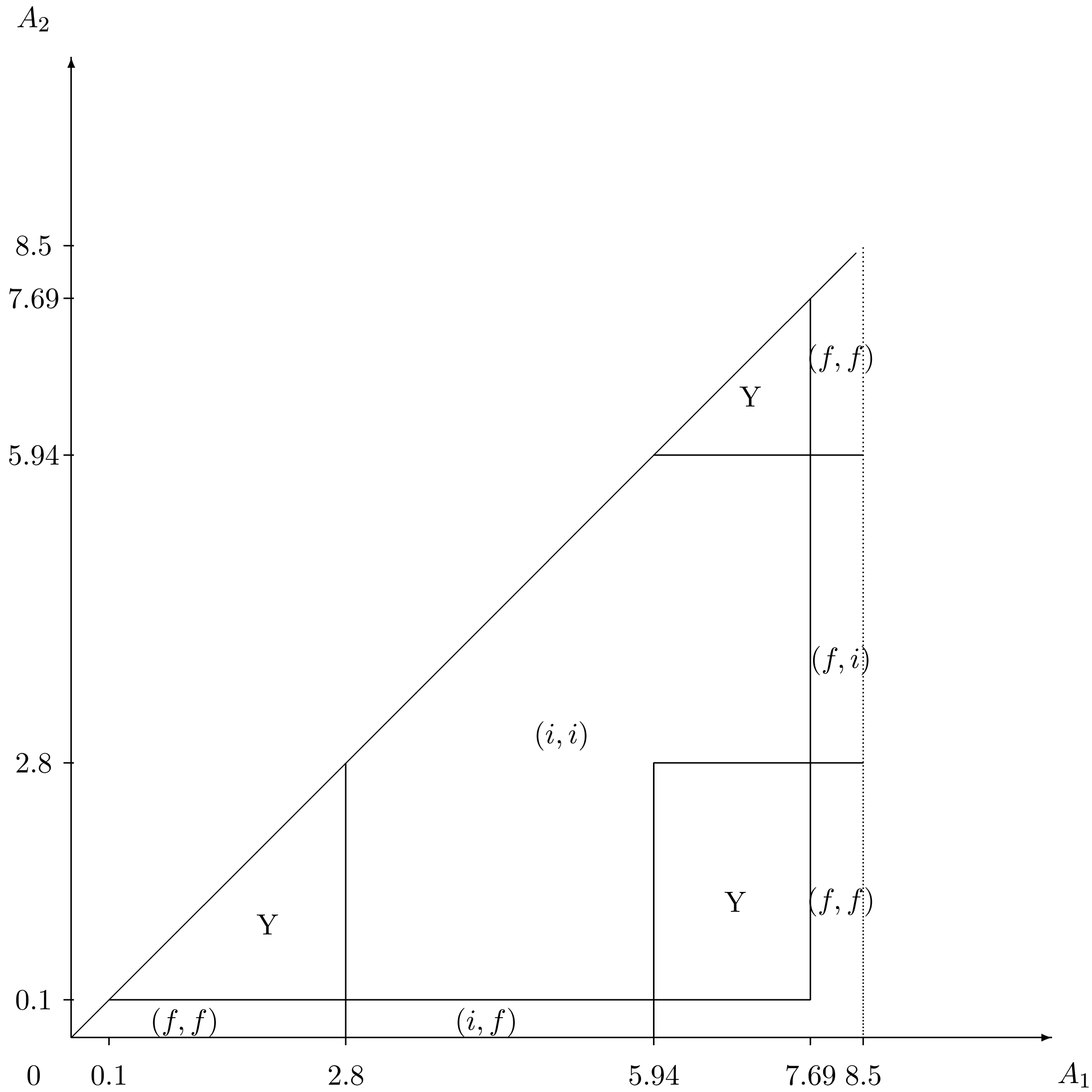

FIGURE $3'$

Equilibrium technological configurations in example 3, $\omega \in \Omega_3$: in Z, (f,i) or (i,f).

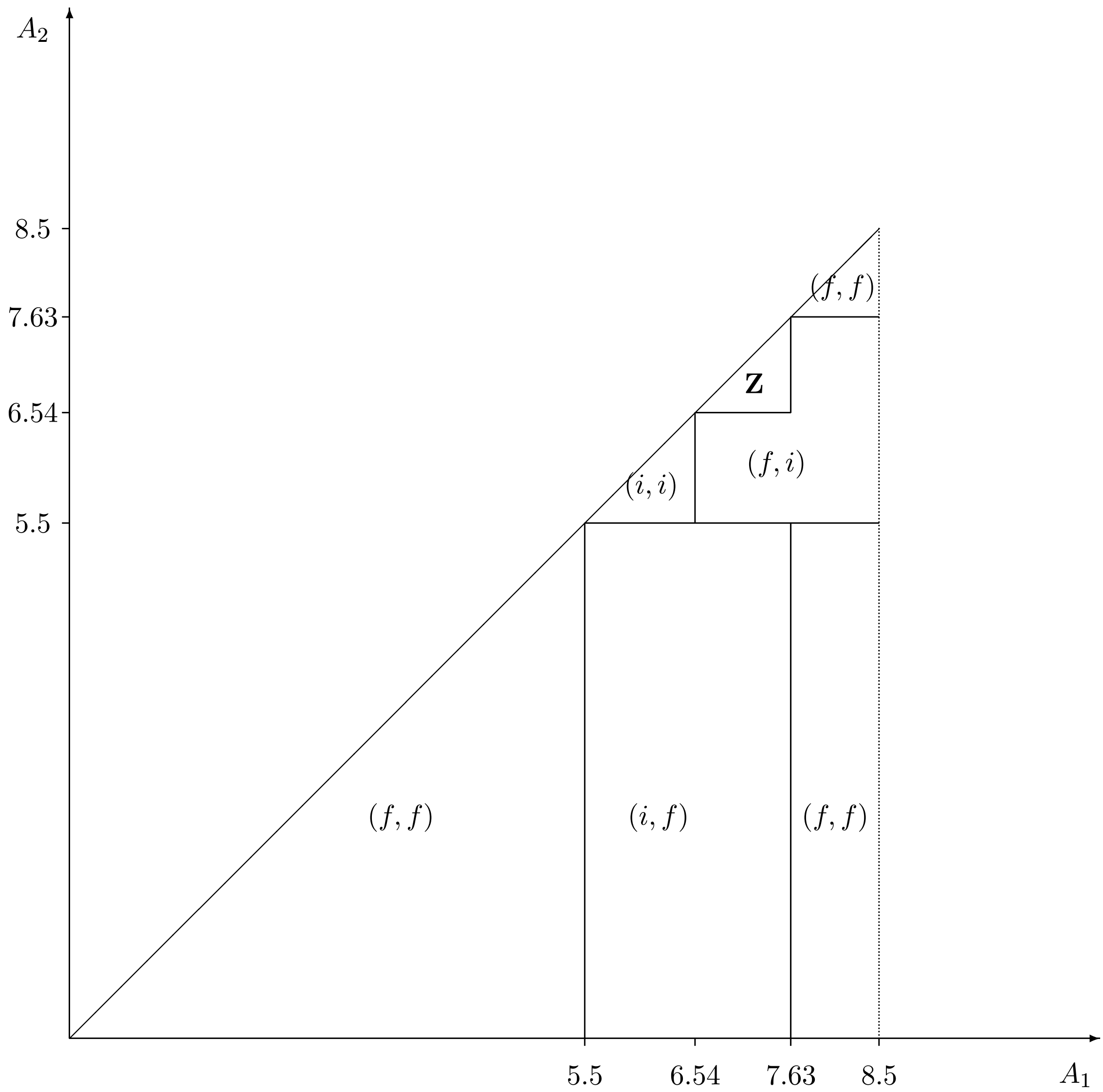

FIGURE $4'$

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