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Abstract

This paper studies the impact of counter-party default risk of forward contracts on a firm´s production and hedging decisions. Using a model of a risk-averse competitive firm under price uncertainty, it derives several fundamental results. If expected profits from forward contracts are zero, the hedge ratio is surprisingly not affected by default risk under general preferences and general price distributions. This robustness result still holds if forwards are subject to additional basis risk. In general, the analysis shows that default risk is no valid reason to reduce hedge ratios if the size of a firm´s forward position does not affect the counter-party´s default probability. However, a firm´s optimal output is negatively affected by default risk and it is generally advisable to hedge default risk with credit derivatives.

1 Introduction

The risk that a counterparty defaults is negligible for most exchange-traded derivatives. However, default risk can be substantial for contracts traded on over-the-counter (OTC) markets, like forwards and swaps. Because OTC derivatives markets have grown rapidly[1] and are crucially important for the management of exchange rate risk, interest rate risk and commodity price risk, the case of a counter-party´s possible default can not be ignored.

Two problems that are connected with derivatives´ default risk have dominated the literature. The first one concerns the systemic risk caused by potential defaults of derivatives contracts and the related issue of regulation of OTC markets. (See e.g. Hentschel and Smith (1994), Schachter (1997), and Bliss and Kaufman (2006)). The second problem concerns the valuation of derivatives contracts subject to default (See e.g. Johnson and Stulz (1987), Bailey and Ng (1991), Hull and White (1995), Jarrow and Turnbull (1995), Duffie and Huang (1996), Klein and Inglis (2001), and Liao and Huang (2005)).

[1] See e.g. Triennial Central Bank Survey (2007).

However, very little is known about a third problem. What is the effect of counter-party default risk on a firm´s risk management strategy? Survey results show that many non-financial firms using derivatives contracts had major concerns about counter-party default risk (See Bodnar, Hayt, and Marston (1996, 1998)), and the current financial crisis has certainly not helped to alleviate these concerns. Therefore, whether and how non-financial firms should adjust their derivatives positions in response to default risk is an important question. This paper addresses this question by developing a prescriptive theory of a firm´s hedging policy with forward contracts that are subject to default.

Many papers have addressed the issue of how firms should design risk management strategies with derivatives, but generally they assume that derivatives contracts are default free.[2] A notable exception is the work by Cummins and Mahul (2008). These authors study a firm´s risk management strategy with default-risky (vulnerable) forwards and options. Their analysis is based on a structural model where default occurs if obligations from derivatives positions exceed the value of the contract writer´s assets. The resulting optimal hedge position with forward contracts consists of three components, a " pure hedge" equal to the output level, a " speculative" component and a " default" component. Moreover, it is shown that under reasonable assumptions the " default" component leads to a reduction in the hedge position, i.e., if the " speculative" component is zero a firm should follow a policy of underhedging its output.

Although Cummins´ and Mahul´s (2008) structural approach clearly has its benefits, this paper follows a reduced form approach which complements and extends their analysis. A main assumption is that the default event is exogenous,[3] but can be correlated with the price risk to be hedged. This assumption leads to a rich set of results, which are in part very different from those obtained by Cummins and Mahul (2008). The main finding of the paper is the following: If the expected profit of forward contracts is zero, default risk does not affect hedge ratios. This result holds for general concave utility functions and general distributions of the

[2]See e.g. Anderson and Danthine (1980, 1981), Moschini and Lapan (1995), Adam-Müller (1997), Chowdhry and Howe (1999), Brown and Toft (2002), Lien and Wong (2002), Chang and Wong (2003), and Wong (2003).

[3]An exogenous default event is a realistic assumption for many hedging activities of non-financial firms since it is quite unlikely that the extent of a single non-financial firm´s hedging activities has an impact on the default probability of major players (counterparties) in the derivatives markets.

price risk. Even with additional basis risk, there is no effect of default risk on hedge ratios. However, as in Cummins and Mahul (2008), default risk reduces a firm´s optimal output. Finally, model extensions are provided that analyze the effects of credit derivatives and a stochastic recovery rate on optimal hedging decisions. In conclusion, the default risk of forward contracts never leads to underhedging, which is an important implication for a firm´s risk management policy.

The remaining part of the paper is structured as follows: Section 2 introduces the basic model, which is an extension of Holthausen´s (1979) model of a competitive firm under price uncertainty and provides the basic characterization of the forward hedge and the output quantity. In Section 3, the basic model is extended to include credit derivatives on forwards and recovery rate risk. Finally, Section 4 summarizes the main results and concludes.

2 The Basic Model

Consider a firm that produces a single good. The firm makes the decision about the output quantity Q at time 0. At time 1, the good is sold in a competitive market for a price $\tilde{P}$, which is a random variable from the perspective of time 0. The firm´s production costs are described by a cost function $c(Q)$ that is increasing, strictly convex and twice differentiable.

Forward contracts are available to the firm as an additional instrument to change the distribution of its profits. These contracts have an exogenous forward price F and can be entered into at time 0. They are written on the price $\tilde{P}$ and expire at time 1. Either long positions or short positions in forwards are allowed, and h denotes the number of contracts sold.

Up to this point, the setting is identical to the one of Holthausen´s (1979) model. The crucial difference lies in the possible default of forward contracts when they expire at time 1. In the case of default, forward contracts become asymmetric instruments. If the value of the forward contracts at expiration is negative, the firm has to fulfill its obligations to the contracts, irrespective of the default of the counterparty. However, if the forward contracts are in the money and the counterparty defaults, the firm looses all profits from forward contracts.[4]

[4]The assumption of a complete loss is relaxed in Subsection *3.2*, which presents a model extension with a stochastic recovery rate.

Under the above assumptions, the firm´s profit for the period from time 0 to time 1 is equal to

$$\tilde{\Pi} = \tilde{P}\,Q - c(Q) + h(F - \tilde{P}) - \tilde{I}\max\left[h(F - \tilde{P}), 0\right]. \tag{1}$$

On the right hand side of equation (1), $\tilde{P}\,Q$ provides the total revenues from selling the good and c(Q) provides the total costs of producing it. The profit or loss from selling h units of default-free forward contracts equals $h(F - \tilde{P})$. A possible default of forward contracts shows up in the last term, $-\tilde{I}\max\left[h(F - \tilde{P}), 0\right]$. Here, the Bernoulli(p) distributed random variable $\tilde{I}$ indicates whether the counterparty of the forward contracts defaults or not. With probability $1 - p$, there is no default on the forward contracts ($I = 0$) and the forwards show the same payoff as default-free contracts. With probability p, there is a default ($I = 1$) and the firm looses all profits from the forward contracts. Note that $\tilde{P}$ and $\tilde{I}$ can in general be stochastically dependent random variables.

The firm solves the following maximization problem:

$$\max_{Q,\,h}\; E[U(\tilde{\Pi})], \quad \text{s.t. } \tilde{\Pi} \text{ as defined in equation (1)}, \tag{2}$$

where $U(\Pi)$ denotes a von Neumann - Morgenstern utility function with $U' > 0$ and $U'' < 0$, i.e., the firm is risk averse.[5] To solve the maximization problem (2), the optimal output quantity $Q^\star$ and the optimal forward position $h^\star$ must be determined. In the following, it is assumed that $Q^\star$ is positive.

2.1 Optimal Hedge Ratio

A well known result for default-free forward contracts states that firms should fully hedge their price exposure if and only if forward contracts earn zero expected profits[6],

[5]The literature has identified many reasons why firms might be risk averse, e.g. taxes, dead-weight costs associated with financial distress, agency problems and the inability of owners or managers to diversify. See e.g. Stulz (1984), Smith and Stulz (1985), Bessembinder (1991), Froot, Scharfstein, and Stein (1993), and DeMarzo and Duffie (1995).

[6]In the literature, the condition of zero expected profits is often stated in terms of “ unbiased forward prices”. However, if forwards are subject to default, unbiased forward prices would no longer lead to zero expected profits of forward contracts, but to negative ones. Therefore, the term “ unbiased forward prices” is not used here.

i.e., the hedge ratio $h^\star/Q^\star$ should be equal to one (See e.g. Holthausen (1979) and Feder, Just, and Schmitz (1980)). If the expected profit from selling forward contracts is positive (negative), i.e., there is an additional speculative component in the firm´s demand for forwards, then the hedge ratio should be greater than one (smaller than one). The following proposition states that the same result holds for default-risky forwards.

Proposition 1: *If and only if the expected profit from selling forward contracts is positive (zero)(negative), the optimal hedge ratio $h^\star/Q^\star$ is greater than one (equal to one)(smaller than one), i.e.,* $F \gtreqless E[\tilde{P}] + E\left[\tilde{I}\ \max[(F - \tilde{P}), 0]\right] \Leftrightarrow h^\star/Q^\star \gtreqless 1.$

Formal proofs of propositions are generally deferred to the appendix. However, to highlight the intuition behind the result, assume that the expected profit of forward contracts is zero and that $Q^\star = 1$. Given these assumptions, Proposition 1 states that the optimal hedge ratio equals $h^\star/Q^\star = 1$.

Why is a situation of a one-to-one hedge optimal for the firm? As an illustration, figure 1 depicts the profit Π and the payoff of a sold forward contract as a function of the price P for the case of a one-to-one hedge. The upper part of the figure refers to the situation when the forward contract does not default, the lower part refers to the situation of default. What happens if the price P is bigger than the forward price F or the forward does not default? In these cases, the one-to-one hedge leads to profits that are equal in all states. However, in all other cases ($P < F$ and forwards default), the number of forwards taken is completely irrelevant for the resulting profit, as the recovery rate is zero by assumption. If expected profits from forwards are zero, what is the best profit distribution a risk averse firm can achieve with forward contracts? It can equalize profits in all states of nature where forward contracts have any impact on profits. As figure 1 shows, this is exactly what the hedge ratio of one does, i.e., figure 1 provides a situation where expected utility is maximized.

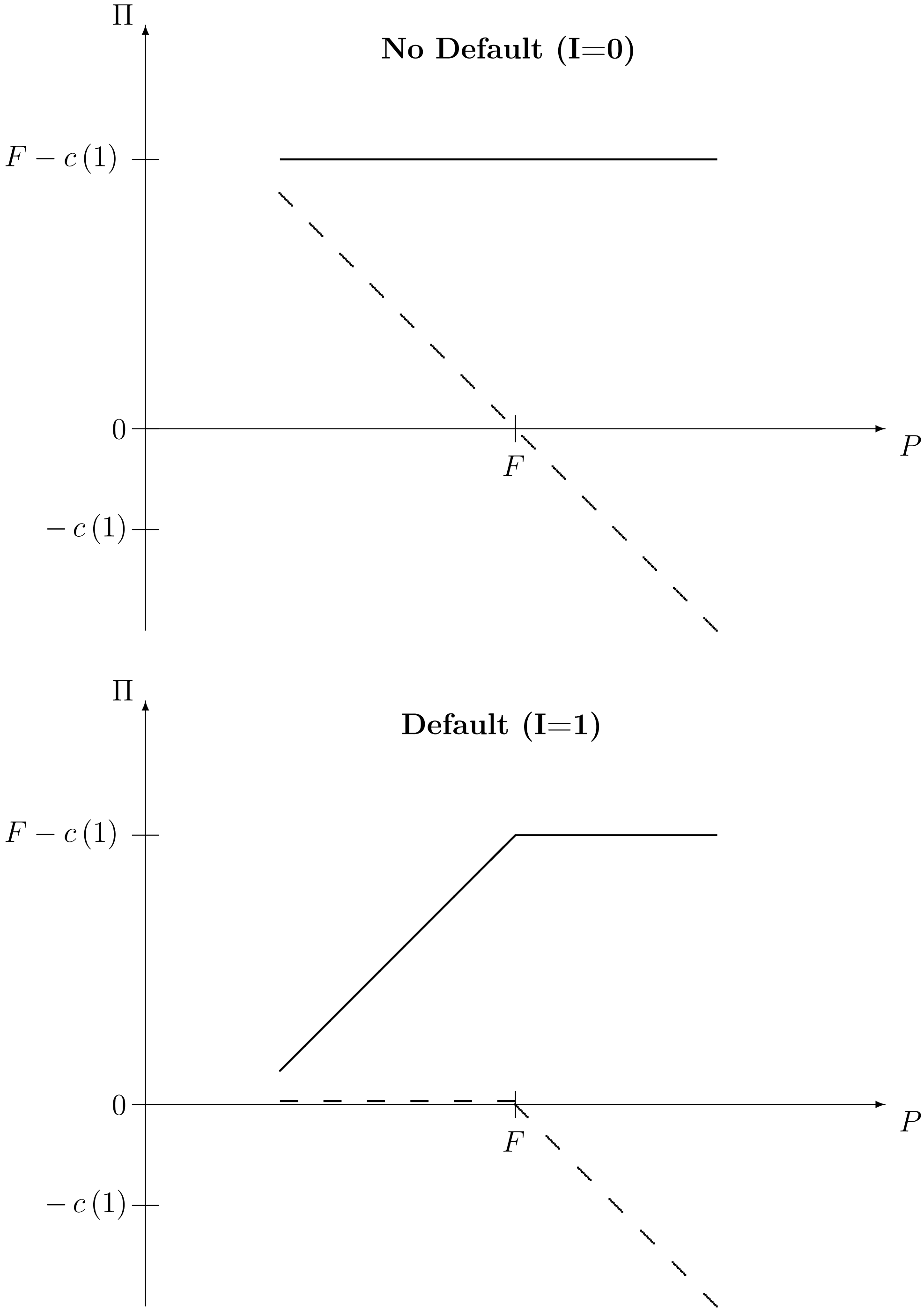

Figure 1: Firm´s profit and payoff of a sold forward contract as functions of P

The figure shows the firm´s profit (solid lines) and the payoff of a sold forward contract (dashed lines) as functions of the price P. The upper part refers to the case when the forward does not default, the lower part refers to the case when the forward does default. The figure assumes that $Q^\star = 1$ and shows a situation where the optimal hedge ratio $h^\star/Q^\star = 1$ is taken.

Proposition 1 provides an interesting robustness result. If forward contracts earn an expected profit of zero[7], the hedge ratio is the same for default-free and default-risky forwards.[8] In particular, the hedge ratio depends neither on the default probability p, nor the distribution of the price $\tilde{P}$, nor the specific form of the utility function. The full hedge is also the variance minimizing hedge. Thus, proposition 1 highlights the importance of a variance minimizing hedge even under general preferences.

Concerning the importance of variance minimization, a well known result from the literature (see Benninga, Eldor, and Zilcha (1983, 1984)) states that under additive basis risk and zero expected profits of (default-free) forwards, a variance minimizing hedge is optimal under general price distributions and concave utility. An analogous result holds for default-risky forwards.[9] Thus, default-risk of forward contracts does not change the optimality of a variance minimizing hedge even under basis risk, provided that expected returns from forwards are zero. In this respect, proposition 1 is robust to the introduction of additive basis risk as analyzed by Benninga, Eldor, and Zilcha (1983, 1984).

One should be aware, however, that proposition 1 does not state that default risk generally has no impact on the hedge ratio. If the expected profit of forward contracts is non-zero, a speculative component comes into play. In this case, the sign of the firm´s extra demand on forward contracts is the same for default-free and default-risky contracts. However, the exact value of the hedge ratio could be different.

[7]Whether it is reasonable for a firm to assume an expected profit of zero depends ultimately on the firm´s information set. Empirical studies on the expectations hypothesis in foreign exchange markets show that it is difficult to reject this hypothesis statistically. See e.g. Bekaert and Hodrick (2001), Roll and Yan (2000), and Maynard and Phillips (2001). Moreover, empirical studies by Adam and Fernando (2006) and Brown, Crabb, and Haushalter (2006) on the hedging behavior of non-financial firms shown that selective hedging (speculation) is not successful on average. Therefore, the assumption of zero expected profits of derivatives contracts is often a reasonable starting point.

[8]Note that this result would also hold for "symmetric default-risky forwards", i.e., forward contracts that do not lead to any payments (neither positive nor negative) in the case of default.

[9]The proof is analogous to the proof of proposition 1 and is available from the author upon request.

2.2 Optimal Output

If output is endogenous, default risk of forward contracts has another effect. With default-free forwards, the marginal production costs equal the forward price at the optimal output level, i.e., $c'(Q^\star) = F$ (See e.g. Holthausen (1979) and Feder, Just and Schmitz (1980)). This well known result identifies the forward price as the focal point of a firm´s production decision, not the future spot price or its distribution. Moreover, the production decision can be taken separately from the decision on the forward position, since the implicit characterization of $Q^\star$ is independent of h. In some respects, just the opposite is true if forwards are subject to default, as stated in the following proposition.

Proposition 2: *If it is optimal to buy (sell) default-risky forward contracts, then the marginal cost of production at the optimal output quantity $Q^\star$ is higher (lower) than the forward price, i.e., $h^\star \lesseqgtr 0 \Rightarrow c'(Q^\star) \gtreqless F$.*

Proposition 2 states that no firm that holds non-zero forward positions should have marginal production costs (at the optimal output level) equal to the forward price. Instead of a point of attraction, as is the case with default-free forwards, the forward price seems to be a point of repulsion. A formal proof of this result can be found in the appendix, but an intuitive reasoning is as follows: For the moment, assume that forward contracts are default-free. If marginal costs were below the forward price, increasing output by a marginal unit and selling a marginal unit in the forward market would generate an extra profit that is risk free, i.e., the firm would leave a free lunch on the table if it would not do so. An analogous argument applies to the case of marginal production costs above the forward price. Reducing output by a marginal unit and buying the marginal unit in the forward market generates a free lunch.

Now assume that forwards are default risky. If marginal production costs equal the forward price and long positions in forwards are held, the firm can increase expected utility by simultaneously increasing output and reducing the forward position by a marginal unit. Such a transaction essentially leaves the firm´s profit unchanged if forwards do not default or are out of the money, but increases the profit if forwards are in the money and default occurs. If the firm chooses an output that leads to marginal costs equal to the forward price, it essentially foregoes a free lottery. By simultaneously reducing the forward position and increasing production by a marginal unit, it would be better off in some future states of the world (forward in the money and default) and would not be worse off in all other states. A similar argument applies to the case with short positions in forwards and marginal production costs equal to the forward price.[10]

If forwards contracts are default risky, the forward price is not the only price variable that influences the choice of the optimal output. Since forwards provide no protection against price risk in the case of default, it is intuitive that output generally depends on the distribution of the spot price at time 1. Moreover, output generally depends on the particular form of the firm´s utility function and it is generally no longer possible to separate the production decision from the hedging decision.

Proposition 2 relates output to the forward price, but does not provide a comparison between the output levels $Q^\star$ that result for default-free and default-risky forward contracts. Similarly, proposition 1 refers to the forward position in proportion to output, but not to the absolute number $h^\star$ of forward contracts. The following proposition 3 sheds some light on the effects of default risk on $Q^\star$ and $h^\star$.

Proposition 3: *If default-free and default-risky forward contracts on the price $\tilde{P}$ have zero expected profits, forward contracts subject to counter-party default risk lead to a lower optimal output level $Q^\star$ than default-free forward contracts.*

Proposition 3 compares a situation where the firm has access to default-free forwards with a situation where only default-risky forwards are available. Both default-free and default-risky contracts have an expected profit of zero from the firm´s perspective. Under this assumption, the firm should sell forward contracts according to proposition 1 and the forward price of default-free contracts is lower than the forward price of default-risky contracts. The assumption of zero expected profits allows us to identify a pure risk effect on $Q^\star$. According to proposition 3, this risk effect leads to a lower optimal output quantity if forwards are subject to default. Intuitively, since forward contracts can no longer achieve a perfect hedge of the price

[10]This kind of argument can not be made if the optimal forward position equals zero. It is likely that in this case marginal costs can be greater than, smaller than or equal to the forward price, depending on the joint distribution of $\tilde{P}$ and $\tilde{I}$ and the particular form of the utility function.

risk, a risk averse firm reduces its price exposure by reducing output. With respect to $h^\star$, propositions 3 and 1 imply that the absolute number of forward contracts sold is lower if forward contracts are default-risky, even though the hedge ratio is not affected. Thus, there is a production effect on the forward position, but not on the hedge ratio.

3 Model Extensions

If forward contracts earn zero expected profits, the hedge ratio is the same for default-free and default-risky forward contracts. Does this robustness result still hold if the firm follows more sophisticated risk management strategies that consider the hedging of default risk or the impact of other sources of risk, like recovery rate risk? The following subsections develop some extensions of the basic model to analyze this question.

3.1 Credit Derivatives on Forwards

Counter-party default risk can in principle be managed by means of derivatives contracts whose payments are contingent on the counterparty´s default.[11] However, how should such a risk management strategy be designed? More specifically, if a credit derivative that is written on the default-risky forward contract is available, how should a firm change its usage of forward contracts and how many credit derivatives should it take?

To answer these questions, consider a first model extension. In addition to forwards, the firm can now enter into a credit derivative contract. The credit contract costs a premium equal to K that is payable at time 0 and promises to cover any losses that arise from the default of a sold forward contract at time 1, i.e., $\tilde{I}\max\Big[(F-\tilde{P}),0\Big]$. However, a credit derivative can itself be default-risky. Thus, it is assumed that the actual payment of the credit contract at time 1 equals $(1-\tilde{J})\tilde{I}\max\Big[(F-\tilde{P}),0\Big]$, where $\tilde{J}$ denotes a Bernoulli(q) distributed random variable that indicates whether the credit derivative does default ($J=1$) or does not default ($J=0$). All three

[11]Markets for different types of such credit derivatives have expanded rapidly over the last years. See e.g. Triennial Central Bank Survey (2007).

random variables $\tilde{P}$, $\tilde{I}$ and $\tilde{J}$ can generally be stochastically dependent. With the additional investment opportunity in credit derivatives, the firm´s profit becomes:

$$\begin{aligned}\tilde{\Pi} &= \tilde{P}\,Q - c(Q) + h(F - \tilde{P}) - \tilde{I}\max\left[h(F-\tilde{P}),0\right] \\ &\quad + z\left[\tilde{I}(1-\tilde{J})\max\left[(F-\tilde{P}),0\right] - K\,(1+r)\right],\end{aligned} \tag{3}$$

where z denotes the number of credit derivatives bought and r is the firm´s risk-free borrowing or lending rate for the period from time 0 to time 1.

The firm has to decide simultaneously about the output, the forward position and the position in the credit derivative, i.e., it solves the following maximization problem:

$$\max_{Q,\,h,\,z}\ E[U(\tilde{\Pi})], \quad \text{s.t. } \tilde{\Pi} \text{ as defined in equation (3).} \tag{4}$$

The first result for the extended model, stated in proposition 4, refers to the hedge ratio $h^\star/Q^\star$.

Proposition 4: *If credit derivatives on forward contracts are available, the optimal hedge ratio $h^\star/Q^\star$ is equal to one if and only if the expected profit from selling forward contracts is zero, i.e.,* $F = E[\tilde{P}] + E\left[\tilde{I}\ \max[(F-\tilde{P}),0]\right] \Leftrightarrow h^\star/Q^\star = 1.$

According to proposition 4, the robustness result of proposition 1 still holds. If forward contracts earn zero expected profits, credit risk does not affect the hedge ratio $h^\star/Q^\star$, even in an extended setting with credit derivatives. In essence, this result is due to the fact that a hedge ratio of one still leads to constant profits if forwards do not default or the firm´s forward position is out of the money. The only difference between a situation with and without credit derivatives lies in the resulting profit level, which equals $F\,Q^\star - c(Q^\star) - z^\star K(1+r)$ in the former case and $F\,Q^\star - c(Q^\star)$ in the latter. If forwards default and the firm´s forward position is in the money, the number of forward contracts h has no impact on profits, irrespective of $z^\star$. Thus, whatever the firm´s optimal position in credit derivatives, the optimal hedge ratio will be $h^\star/Q^\star = 1$.

Another interesting issue that can be addressed by means of the extended model is the usage of credit derivatives. The next proposition refers to this issue, in particular to the ratio $z^\star/h^\star$.

Proposition 5: *(i) If expected profits of forward contracts are zero and credit derivatives are default free, the ratio $z^\star/h^\star$ is equal to one if and only if expected profits of credit derivatives are zero, i.e.,* $K(1+r) = E\left[\tilde{I}\ \max[(F-\tilde{P}),0]\right] \Leftrightarrow z^\star/h^\star = 1.$
(ii) If expected profits of forward contracts are zero and credit derivatives are default risky, the ratio $z^\star/h^\star$ is greater than zero and smaller than one if expected profits of the credit derivative are zero, i.e., $K(1+r) = E\left[\tilde{I}\,(1-\tilde{J})\ \max[(F-\tilde{P}),0]\right] \Rightarrow$
$0 < z^\star/h^\star < 1.$

The first part of proposition 5 considers a reference case with default-free credit derivatives. If default-free credit derivatives are available, we are essentially back in a world with default-free forward contracts. A derivatives portfolio that combines a short position of one unit of default-risky forwards with a long position of one unit of default-free credit contracts earns a profit equal to $F - K(1+r) - \tilde{P}$, the same profit that a short position in a default-free forward contract with forward price $F - K(1+r)$ would earn. Since it is possible to eliminate price risk, a full hedge is optimal if expected profits from derivatives contracts are zero. The availability of default-free credit derivatives also implies that the optimal production quantity does not depend on the distribution of $\tilde{P}$ and the specific form of the utility function. It is easy to show that $c'(Q^\star) = F - K(1+r)$ must hold.

The second part of proposition 5 considers the more realistic case of default-risky credit derivatives. A first message is that every risk averse firm should buy a positive amount of credit derivatives if expected profits from these contracts are zero. The availability of credit derivatives is utility increasing for every risk averse firm.

A second message is that firms should not try to fully hedge credit risk with credit contracts, i.e., a firm should choose a ratio $z^\star/h^\star$ smaller than one.[12] Since credit derivatives are subject to default, risk can not be totally avoided, but only transferred by means of different instruments. Stated differently, the second part of

[12]This finding is in line with other results in the literature, derived under the assumption of both price risk and quantity risk. For example, Adam-Müller (1997) shows that under independent price and quantity risk underhedging results, if forward markets are unbiased and $U'''(\Pi) > 0$.

proposition 5 says that it is optimal to diversify credit risk. Consider the extreme cases $z/h = 0$ and $z/h = 1$. In the first case, only forward contracts with forward price F and default probability $E(\tilde{I})$ are held. In the second case, only "synthetic" forward contracts with forward price $F - K(1 + r)$ and default probability $E(\tilde{I}\tilde{J})$ are held. However, both strategies are not optimal. An optimal derivatives position consists of a mixture of the two "types" of forward contracts. Since the default risks of the two "types" of contracts are not perfectly correlated[13], i.e., $Corr(\tilde{I}, \tilde{I}\tilde{J}) < 1$, this kind of diversification is intuitively reasonable.

3.2 Recovery Rate Risk

A firm´s profit uncertainty due to a possible default of forward contracts has generally two sources. The first one is the uncertainty on whether a default will occur. The second one is the uncertainty on the amount that is lost in the case of a default. In the model variants analyzed so far, the "loss given default" depends on a single risk factor, the price $\tilde{P}$. However, a more realistic approach would also consider another risk factor, a stochastic recovery rate. This subsection provides a second model extension that explores the impact of recovery rate risk on the hedge ratio $h^\star/Q^\star$.

Consider the setting of the basic model, but assume that in the case of default only a fraction $(1 - \tilde{R})$ of the gains from forward contracts is lost. The random variable $\tilde{R}$ denotes the recovery rate of a forward contract and can take values between zero and one. It need not be stochastically independent of $\tilde{P}$ and $\tilde{I}$. With a stochastic recovery rate of defaulted forward contracts, the firm´s profit becomes:

$$\tilde{\Pi} = \tilde{P}Q - c(Q) + h(F - \tilde{P}) - \tilde{I}(1 - \tilde{R}) \max\left[h(F - \tilde{P}), 0\right]. \tag{5}$$

Note that the model by Holthausen (1979) results as a special case for $R \equiv 1$ and the basic model of Section 2 results as a special case for $R \equiv 0$. In the following, a positive probability that $\tilde{R}$ is strictly smaller than one and greater than zero is assumed. Proposition 6 characterizes the optimal hedge ratio $h^\star/Q^\star$ for the case of zero expected profits.

[13] A correlation of one occurs only in the uninteresting case of a useless credit derivative that generally defaults if the forward contract defaults.

Proposition 6: *If forward contracts have a stochastic recovery rate $\tilde{R}$ and the expected profit from selling forward contracts is zero, the hedge ratio $h^\star/Q^\star$ is greater than one, i.e.,* $F = E[\tilde{P}] + E\left[\tilde{I}(1-\tilde{R})\ \max[(F-\tilde{P}),0]\right] \Rightarrow h^\star/Q^\star > 1.$

In the model variants presented so far, default risk has no effect on the hedge ratio when expected returns from forwards are zero. According to proposition 6, a firm´s reaction to default risk should be to sell even more forward contracts, i.e., take a larger forward position in absolute terms. At first sight, this result might be astonishing. Should we not expect that a firm should reduce its use of an instrument that makes the firm´s profit sensitive to additional sources of risk?

Figure 2 provides some intuition for the benefits of overhedging, i.e., the choice of a hedge ratio greater than one, if the recovery rate lies in the interval $(0, 1)$. Similar to figure 1, figure 2 depicts the firm´s profit Π and the payoff of a sold forward contract as a function of the price P. Again, it is assumed that $Q^\star = 1$ and $h/Q^\star = 1$. However, in contrast to figure 1, there is a recovery rate of $R = 0.5$. With a full hedge, constant profits of $F - c(1)$ are obtained if the forward does not default or $P \geq F$. However, if the forward defaults and $P < F$, the profit strictly increases with P and the payoff of the forward contract strictly decreases with P. In contrast to figure 1, figure 2 shows a suboptimal situation for the firm. The crucial difference between a recovery rate of zero and a positive recovery rate is that in the latter case forwards offer some payments (positive recovery) in the worst states of nature, when higher profits are most beneficial. These states are those with a low price and a defaulting forward contract. Thus, the fact that some gains from forward contracts can be realized even in the case of default offers an opportunity to shift some profits from high profit states to low profit states by means of overhedging. Such an overhedging makes the profit (on average) an inversely V-shaped function of the price P. This observation is in line with some results of the literature that has analyzed problems with similar structure.[14]

In practice, the choice of a hedge ratio greater than one might be difficult to defend, in particular if the reasoning behind it relies on the uncertain gains from defaulted forward contracts. From this perspective, it is an important question whether the quantitative effects of a stochastic recovery rate on hedge ratios are generally so small that they can be safely neglected in practice.

[14]See, for example, Chang and Wong (2003), p. 561.

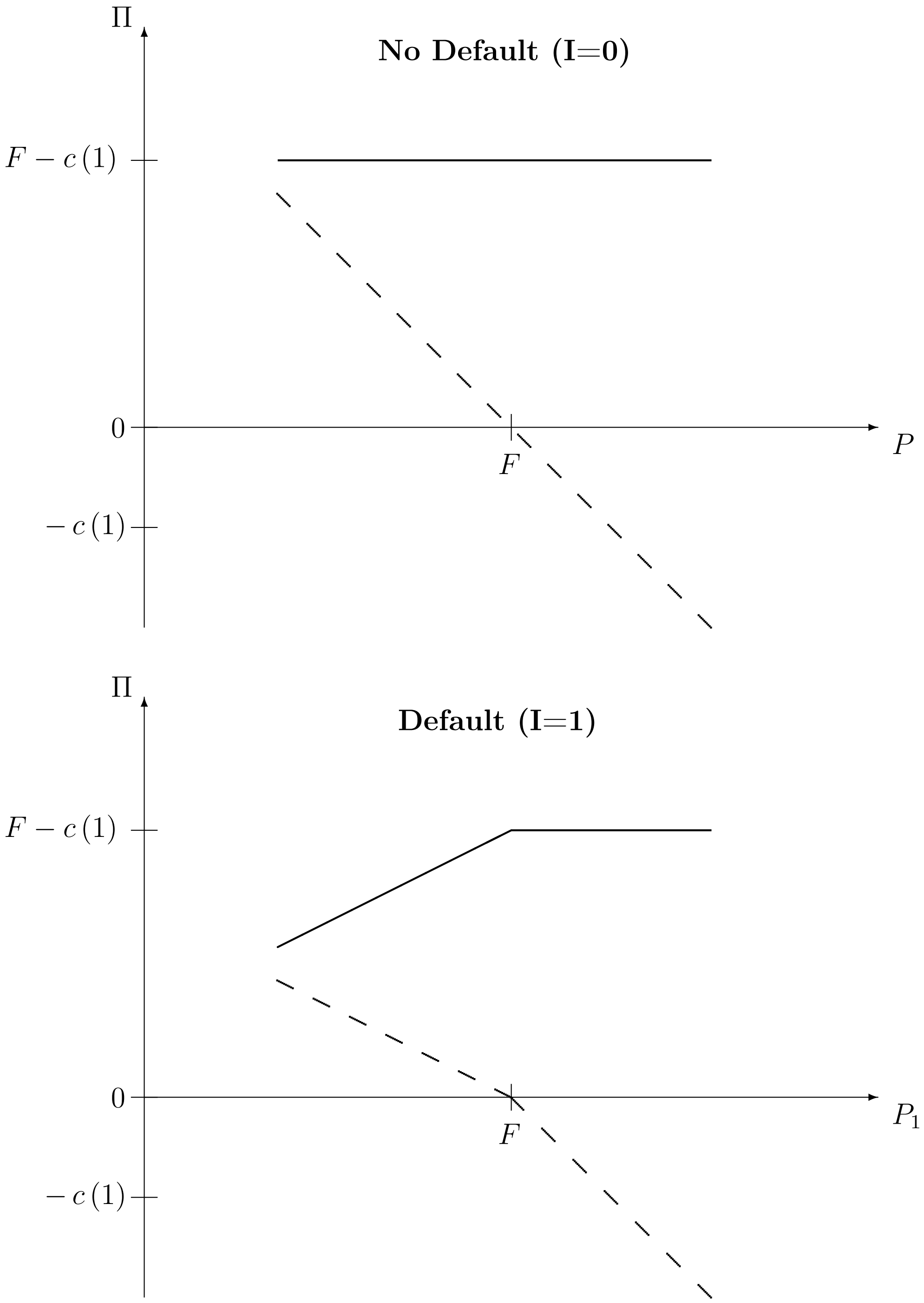

Figure 2: Firm´s profit and payoff of a sold forward contract with recovery rate $R = 0.5$ as functions of P

The figure shows the firm´s profit (solid lines) and the payoff of a sold forward contract with recovery rate $R = 0.5$ (dashed lines) as functions of the price P. The upper part refers to the case when the forward does not default, the lower part refers to the case when the forward defaults. The figure assumes that $Q^\star = 1$ and shows a situation with a hedge ratio $h/Q^\star = 1$, which is not optimal.

This question was analyzed by means of a comparative static analysis based on a utility function with constant absolute risk aversion (CARA) and a log-normal price distribution with an expectation of 1 and a volatility of 20%. The effects of different levels of absolute risk aversion (coefficients equal to 1, 5 or 10), different default probabilities of forwards (1%, 2% or 5%) and different recovery rates (0.1, 0.2, ... , 0.9) were analyzed in this setting. The results show that deviations from a hedge ratio of one are not economically significant. Even with an absolute risk aversion coefficient of 10 and a default probability of 5%, the resulting maximum hedge ratio is only 1.014.

4 Summary and Conclusions

Many non-financial firms that use OTC derivatives are confronted with the problem of counter-party default risk. Therefore, how firms should consider default risk of derivatives contracts in their risk management strategies is an important question. This paper makes a step towards an answer. Within a model of a risk-averse competitive firm under price uncertainty, it derives several fundamental results on a firm´s optimal forward position and output quantity if forward contracts are subject to an exogenous default event.

A first set of results identifies the conditions under which exogenous default risk does not matter. The basic result states that the hedge ratio is not affected by default risk if forward contracts earn zero expected profits. In this case, full hedging is generally optimal. A model extension shows that an important robustness result by Benninga, Eldor and Zilcha (1983, 1984) still holds for default-risky contracts. If there is an additive basis risk and the expected profits of forwards are zero, a variance minimizing hedge ratio is optimal for general concave utility functions and general price distributions, irrespective of the default risk. Thus, variance minimizing hedging strategies, that are attractive with respect to tractability and implementation, can be theoretically justified under rather general conditions.

The analysis of this paper leads to a clear recommendation: Firms should not reduce hedge ratios in response to exogenous default risk. On the contrary, an extended model with a stochastic recovery rate suggests that one should rather increase hedge ratios. The literature has identified several valid reasons for underhedging, like quantity risk (Benninga, Eldor, and Zilcha (1985) and Adam-Müller (1997)), specific types of basis risk (Briys, Crouhy, and Schlesinger (1993) and Adam-Müller (2006)), liquidity risk (Korn (2004)) and a comparative advantage in risk-taking (Stulz(1996)). However, exogenous default risk is not one of them. This conclusion is strikingly different from the one that could be drawn from Cummins´ and Mahul´s (2008) structural model with endogenous default. Two reasons are responsible for this difference: First, if the (absolute) size of a forward position affects the probability of default, there is an incentive to reduce hedge positions. Second, one must be careful to distinguish between the "speculative" component and the "default" component of a hedge. If one would use the unbiasedness of forward prices as a reference point, default-risky forwards would have a negative expected return, i.e., there would be a speculative motive to reduce (absolute) forward positions. However, if zero expected profits from forward contracts are seen as the reference point, which is explicitly done in this paper, one can draw conclusions about the pure default component of a hedge.

This paper has also shown in which respect default risk does matter. Even if expected profits of forwards are zero, the number of forward contracts sold will generally be reduced by default risk if output is endogenous. The reason is that a firm should produce less if it has to rely on default-risky forward contracts instead of default-free ones. If the expected profits of forward contracts are non-zero, default risk might also affect the speculative component of a firm´s forward position. Moreover, with default-risky forwards, it is no longer generally possible to determine the optimal output quantity independently from the optimal forward position. The forward price is no longer the only price information that affects production.

If forward contracts are subject to default, credit derivatives written on forwards should be used to some extent. Essentially, a firm should diversify between the default risk of the forward and the default risk of the credit derivative. This result of the paper suggests that it might also be valuable to diversify between different counterparties in the forward market. Finally, the set of contracts available to the firm could be extended further. One could think of plain vanilla options in addition to forwards or even tailor made exotic derivatives.[15] However, this question of optimal contract design is left for future research.

[15]See Moschini and Lapan (1995), Lien and Wong (2002), Chang and Wong (2003), and Wong (2003) for models with forwards and options. Brown and Toft (2002) and Cummins and Mahul (2008) consider optimal taylor made contracts.

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Appendix

Proof of Proposition 1:

The proposition is proved in two steps. In the first step, I show that the stated equivalence holds under the assumption that $h^\star \geq 0$. The second step completes the proof under the assumption that $h^\star < 0$.

Step 1: Assume that $h \geq 0$ and consider the first derivative of the firm´s objective function $E[U(\tilde{\Pi})]$ with respect to h, evaluated at $h = Q^\star$:

$$E\left[U'(\tilde{\Pi})\left[(F-\tilde{P}) - \tilde{I}\max[(F-\tilde{P}),0]\right] \mid h = Q^\star\right].$$

The firm´s objective function is strictly concave in h for non-negative values of h under the stated assumption that $U'' < 0$. Therefore, under the additional assumption that $h^\star \geq 0$, the following equivalence holds:

$$E\left[U'(\tilde{\Pi})\left[(F-\tilde{P}) - \tilde{I}\max[(F-\tilde{P}),0]\right] \mid h = Q^\star\right] \gtreqqless 0 \qquad (6)$$

$$\Leftrightarrow \qquad h^\star/Q^\star \gtreqqless 1. \qquad (7)$$

The expectation on the left hand side of inequality (6) can be rewritten as follows:

$$\begin{aligned} & E\left[U'(\tilde{\Pi})\left[(F-\tilde{P}) - \tilde{I}\max[(F-\tilde{P}),0]\right] \mid h = Q^\star\right] \qquad (8) \\ = \; & E\left[E\left[U'(\tilde{\Pi})\left[(F-\tilde{P}) - \tilde{I}\max[(F-\tilde{P}),0]\right] \mid h = Q^\star\right] \mid \tilde{I}\right] \\ = \; & p\,E\left[U'(\tilde{\Pi})\left[(F-\tilde{P}) - \max[(F-\tilde{P}),0]\right] \mid h = Q^\star,\, I = 1\right] \\ & +(1-p)\,E\left[U'(\tilde{\Pi})(F-\tilde{P}) \mid h = Q^\star,\, I = 0\right]. \end{aligned}$$

If $h = Q^\star$ and $I = 0$ (no default), the profit Π equals $FQ^\star - c(Q^\star)$, i.e., it is not stochastic. Thus, the marginal utility $U'(\Pi \mid h = Q^\star,\, I = 0)$ is a constant function of P. In the case of default ($h = Q^\star, I = 1$), the same constant function results for $P \geq F$. For $P < F$, the marginal utility decreases with increasing P, but $(F - P) - \max[(F - P), 0]$ is always equal to zero. Therefore, the marginal utility $U'(\Pi|\, h = Q^\star,\, I = 0)$ can be written in front of the expectations in the last two lines of equation (8):

$$
\begin{aligned}
& p\, E\left[U'(\tilde{\Pi}) \left[(F - \tilde{P}) - \max[(F - \tilde{P}), 0]\right] |\, h = Q^\star,\, I = 1\right] && (9)\\
& +(1 - p)\, E\left[U'(\tilde{\Pi})(F - \tilde{P})|\, h = Q^\star,\, I = 0\right] \\
= \;& p\, U'(\Pi|\, h = Q^\star,\, I = 0)\, E\left[(F - \tilde{P}) - \max[(F - \tilde{P}), 0]|\, I = 1\right] && (10)\\
& +(1 - p)\, U'(\Pi|\, h = Q^\star,\, I = 0)\, E\left[(F - \tilde{P})|\, I = 0\right].
\end{aligned}
$$

Since $U'(\Pi|\, h = Q^\star,\, I = 0)$ is positive, the following equivalence holds:

$$
\begin{aligned}
& p\, U'(\Pi|\, h = Q^\star,\, I = 0)\, E\left[(F - \tilde{P}) - \max[(F - \tilde{P}), 0]|\, I = 1\right] \\
& \quad +(1 - p)\, U'(\Pi|\, h = Q^\star,\, I = 0)\, E\left[(F - \tilde{P})|\, I = 0\right] \gtreqless 0 \\
\Leftrightarrow \quad & p\, E\left[(F - \tilde{P}) - \max[(F - \tilde{P}), 0]|\, I = 1\right] && (11)\\
& \quad +(1 - p)\, E\left[(F - \tilde{P})|\, I = 0\right] \gtreqless 0.
\end{aligned}
$$

The terms on the left hand side of inequality (11) can be written in more compact form as

$$
\begin{aligned}
& p\, E\left[(F - \tilde{P}) - \max[(F - \tilde{P}), 0]|\, I = 1\right] \\
& +(1 - p)\, E\left[(F - \tilde{P})|\, I = 0\right] \\
= \;& E\left[E\left[(F - \tilde{P}) - \tilde{I} \max[(F - \tilde{P}), 0]\right] |\, \tilde{I}\right] \\
= \;& E\left[(F - \tilde{P}) - \tilde{I}\, \max[(F - \tilde{P}), 0]\right]. && (12)
\end{aligned}
$$

Using expression (12), the following equivalence has been shown:

$$
\begin{aligned}
& E\left[U'(\tilde{\Pi}) \left[(F - \tilde{P}) - \tilde{I} \max[(F - \tilde{P}), 0]\right] |\, h = Q^\star\right] \gtreqless 0 && (13)\\
\Leftrightarrow \quad & E\left[(F - \tilde{P}) - \tilde{I}\, \max[(F - \tilde{P}), 0]\right] \gtreqless 0. && (14)
\end{aligned}
$$

The desired result follows from the equivalence of equations (6) and (7) and the equivalence of equations (13) and (14), i.e.,

$$\begin{aligned} F &\gtreqqless E[\tilde{P}] + E\left[\tilde{I}\ \max[(F-\tilde{P}),0]\right] \\ \Leftrightarrow h^{\star}/Q^{\star} &\gtreqqless 1. \end{aligned}$$

Step 2: Now assume that $h^{\star} < 0$. To complete the proof of the proposition, it remains to show that $F < E[\tilde{P}] + E\left[\tilde{I}\ \max[(F-\tilde{P}),0]\right]$ must hold in this case.

For a negative value of h, the profit in equation (1) becomes

$$\tilde{\Pi} = \tilde{P}Q - c(Q) + h(F-\tilde{P}) - h\,\tilde{I}\min\left[(F-\tilde{P}),0\right]. \tag{15}$$

Since $h^{\star}$ is assumed to be negative, it must satisfy the following necessary condition:

$$E\left[U'(\tilde{\Pi})\left[(F-\tilde{P}) - \tilde{I}\min[(F-\tilde{P}),0]\right]\right] = 0. \tag{16}$$

The left hand side of equation (16) can be rewritten as follows:

$$\begin{aligned} & E\left[U'(\tilde{\Pi})\left[(F-\tilde{P}) - \tilde{I}\min[(F-\tilde{P}),0]\right]\right] \qquad (17) \\ = \; & E\left[U'(\tilde{\Pi})(F-\tilde{P})\right] - E\left[U'(\tilde{\Pi})\,\tilde{I}\min[(F-\tilde{P}),0]\right]. \end{aligned}$$

Since $U'(\tilde{\Pi})$ is a random variable with positive support and $\tilde{I}\min[(F-\tilde{P}),0]$ is a random variable with non-positive support, the first order condition (16) implies that $E\left[U'(\tilde{\Pi})(F-\tilde{P})\right]$ must be negative.

Now define the random variable $\tilde{Z}$ as follows:

$$\tilde{Z} = \tilde{P}Q - c(Q) + h(F-\tilde{P}) - h\ \min\left[(F-\tilde{P}),0\right]. \tag{18}$$

Note that in all possible states of the world $\tilde{Z}$ is smaller than or equal to the random variable $\tilde{\Pi}$. If $\tilde{P}$ takes values smaller than or equal to F, or $I=1$, then $\tilde{Z}$ and $\tilde{\Pi}$ take equal values. If $\tilde{P}$ takes values bigger than F and $I=0$, then $\tilde{Z}$ takes smaller values than $\tilde{\Pi}$ under our assumption of a negative hedge position h. Therefore, in all the latter states of the world we would have $U'(\Pi)(F-P) > U'(Z)(F-P)$, since $(F-P)$ is negative and $U'(Z) > U'(\Pi)$. This argument implies that

$$E\left[U'(\tilde{\Pi})(F-\tilde{P})\right] > E\left[U'(\tilde{Z})(F-\tilde{P})\right]. \tag{19}$$

Using inequality (19) and the optimality condition (16), we can now conclude that $E\left[U'(\tilde{Z})(F-\tilde{P})\right]$ must be negative. The expectation under question can be written as follows:

$$\begin{aligned} & E\left[U'(\tilde{Z})(F-\tilde{P})\right] \\ = \; & E\left[U'(\tilde{Z})\right] E(F-\tilde{P}) - Cov(U'(\tilde{Z}),\tilde{P}) \end{aligned}$$

The covariance $Cov(U'(\tilde{Z}),\tilde{P})$ is negative. To see this, note that for negative h the random variable $\tilde{Z}$, as given in equation (18), strictly increases with P. Also note that $\tilde{Z}$ does not depend on any other random variable. Since marginal utility strictly decreases with profits, the covariance term must be negative.

We can now conclude that for equation (16) to hold, $E\left[U'(\tilde{Z})\right] E(F-\tilde{P})$ must be negative. Since marginal utility is always positive, this condition implies that F must be smaller than $E(\tilde{P})$. Therefore, it has been shown that $F < E[\tilde{P}] + E\left[\tilde{I}\max[(F-\tilde{P}),0]\right]$ is necessary to give a firm the incentive to hold a long positions in forwards. □

Proof of Proposition 2:

The first order condition with respect to the output quantity Q reads:

$$\begin{aligned} & E\left[U'(\tilde{\Pi})(\tilde{P}-c'(Q))\right] = 0 \\ \Leftrightarrow \quad & c'(Q) = \frac{E\left[U'(\tilde{\Pi})\tilde{P}\right]}{E\left[U'(\tilde{\Pi})\right]}. \end{aligned} \tag{20}$$

If $h^\star$ is greater than zero, the following first order condition holds:

$$
\begin{aligned}
& E\left[U'(\tilde{\Pi})\left[(F-\tilde{P})-\tilde{I}max[F-\tilde{P},0]\right]\right]=0 \\
\Leftrightarrow \quad & F-\frac{E\left[U'(\tilde{\Pi})\,\tilde{I}\,max[F-\tilde{P},0]\right]}{E[U'(\tilde{\Pi})]}=\frac{E\left[U'(\tilde{\Pi})\tilde{P}\right]}{E\left[U'(\tilde{\Pi})\right]}.
\end{aligned} \tag{21}
$$

Since the two expressions on the right hand sides of equations (20) and (21) are equal, the following expression for the marginal costs results:

$$
c'(Q)=F-\frac{E\left[U'(\tilde{\Pi})\,\tilde{I}\,max[F-\tilde{P},0]\right]}{E[U'(\tilde{\Pi})]}. \tag{22}
$$

The random variable $U'(\tilde{\Pi})\,\tilde{I}\,max[F-\tilde{P},0]$ takes a positive value at least for one realization of $\tilde{P}$, as long as the forward contract can default and does not provide an arbitrage opportunity. However, $U'(\tilde{\Pi})\,\tilde{I}\,max[F-\tilde{P},0]$ can never be negative. Therefore, the expectation of $U'(\tilde{\Pi})\,\tilde{I}\,max[F-\tilde{P},0]$ must be positive and $c'(Q)<F_0$ holds, which proofs the result for $h^\star>0$.

The proof for $h^\star<0$ is analogous. If $h^\star<0$, the following first order condition holds:

$$
\begin{aligned}
& E\left[U'(\tilde{\Pi})\left[(F-\tilde{P})-\tilde{I}min[F-\tilde{P},0]\right]\right]=0 \\
\Leftrightarrow \quad & F-\frac{E\left[U'(\tilde{\Pi})\,\tilde{I}\,min[F-\tilde{P},0]\right]}{E[U'(\tilde{\Pi})]}=\frac{E\left[U'(\tilde{\Pi})\tilde{P}\right]}{E\left[U'(\tilde{\Pi})\right]}.
\end{aligned} \tag{23}
$$

Equations (20) and (23) imply that

$$
c'(Q)=F-\frac{E\left[U'(\tilde{\Pi})\,\tilde{I}\,min[F-\tilde{P},0]\right]}{E[U'(\tilde{\Pi})]}. \tag{24}
$$

Since $U'(\tilde{\Pi})\,\tilde{I}\,min[F-\tilde{P},0]$ is a non-positive random variable that is negative at least in one state, provided the forward contract can default and does not provide an arbitrage opportunity, its expectation is negative. Thus, is follows from equation (24) that $c'(Q)>F$. □

Proof of Proposition 3:

It is well known that for a firm that has access to default-free forwards, marginal costs equal the forward price at the optimal output level. Therefore, if expected profits from forwards are zero, we obtain $c'(Q) = F = E[\tilde{P}]$ for the case of default-free forwards.

We will show that for the case of default-risky forwards, marginal production costs of $E[\tilde{P}]$ lead to an incentive to reduce output, i.e., the optimal output is smaller than in the case with default-free forwards.

Since we know from proposition 1 that $h^* = Q$ if expected returns from forwards are zero, we have to show that

$$\begin{aligned}
& E\left[U'(\tilde{\Pi})\left((\tilde{P} - c'(Q) + (F - \tilde{P}) - \tilde{I}\,max[F - \tilde{P}, 0]\right)|h = Q, c'(Q) = E[\tilde{P}]\right] < 0 \\
\Leftrightarrow\ & E\left[U'(\tilde{\Pi})\left((\tilde{P} - E[\tilde{P}] + (F - \tilde{P}) - \tilde{I}\,max[F - \tilde{P}, 0]\right)|h = Q, c'(Q) = E[\tilde{P}]\right] < 0 \\
\Leftrightarrow\ & E\left[U'(\tilde{\Pi})\left(-\tilde{I}\,max[F - \tilde{P}, 0] + E\left[\tilde{I}\,max[F - \tilde{P}, 0]\right]\right)|h = Q, c'(Q) = E[\tilde{P}]\right] < 0 \\
\Leftrightarrow\ & Cov\left[U'(\tilde{\Pi}), -\tilde{I}\,max[F - \tilde{P}, 0]|h = Q, c'(Q) = E[\tilde{P}]\right] < 0 \qquad (25)
\end{aligned}$$

Note that the second equivalence uses the fact that $F = E[\tilde{P}] + E[\tilde{I}\,max[F - \tilde{P}, 0]]$, i.e., expected profits from forwards are zero.

To see that the covariance on the left hand side of inequality (25) is indeed negative, recall that under our assumptions the profit $\tilde{\Pi}$ takes the following form:

$$\tilde{\Pi} = Q\,F - c(Q) - Q\,\tilde{I}\,max[F - \tilde{P}, 0]. \qquad (26)$$

Since the profit strictly increases with increasing realizations of the random variable $-\tilde{I}\,max[F - \tilde{P}, 0]$, marginal utility strictly decreases. Therefore, the covariance between marginal utility and $-\tilde{I}\,max[F - \tilde{P}, 0]$ must be negative. $\square$

Proof of Proposition 4:

The proof is completely analogous to the proof of proposition 1. However, some comments on the essential step of the proof, the equality of expressions (9) and (10), might be useful. In the more general model with credit derivatives, if $h = Q^\star$ and $I = 0$ (no default), the profit Π equals $FQ^\star - c(Q^\star) - z^\star K(1+r)$, i.e., the profit is still nonstochastic and marginal utility $U'(\Pi|\, h = Q^\star,\, I = 0)$ is a constant function of P. In the case of default $(h = Q^\star, I = 1)$, the same constant function results for $P \geq F$. Since $(F - P) - \max[(F - P), 0]$ is always equal to zero for $P < F$, the marginal utility $U'(\Pi|\, h = Q^\star,\, I = 0)$ can still be written in front of the expectations in the last two lines of equation (8). Expressions (9) and (10) are equal even in the more general model with credit derivatives. □

Proof of Proposition 5:

First, consider the second part of the proposition. It follows from proposition 4 that $h^\star = Q^\star > 0$ under the assumption of zero expected profits of forward contracts. Thus, the ratio $z^\star/h^\star$ is always defined. Since the firm´s objective function is strictly concave in z over the whole real line, the ratio $z^\star/h^\star$ is smaller than one if the first derivative of $E[U(\tilde{\Pi})]$ with respect to z is negative for $z = h^\star$. Therefore, one has to show that the following inequality holds:

$$E\left[U'(\tilde{\Pi})\left[\tilde{I}(1-\tilde{J})\max[(F-\tilde{P}),0] - K(1+r)\right] |\, z = h^\star\right] < 0. \qquad (27)$$

The left hand side of inequality (27) can be written as

$$\begin{aligned}
& E\left[U'(\tilde{\Pi})\left[\tilde{I}(1-\tilde{J})\max[(F-\tilde{P}),0] - K(1+r)\right] |\, z = h^\star\right] \\
= \; & E\left[E\left[U'(\tilde{\Pi})\left[\tilde{I}(1-\tilde{J})\max[(F-\tilde{P}),0] - K(1+r)\right] |\, z = h^\star\right] |\, \tilde{I}, \tilde{J}\right] \\
= \; & -p_{I=1,J=1} E\left[U'(\tilde{\Pi})K(1+r)|\, z = h^\star, I = 1, J = 1\right] \qquad (28) \\
& + p_{I=1,J=0} E\left[U'(\tilde{\Pi})\max[(F-\tilde{P}),0] - K(1+r)|\, z = h^\star, I = 1, J = 0\right] \\
& - p_{I=0,J=1} E\left[U'(\tilde{\Pi})K(1+r)|\, z = h^\star, I = 0, J = 1\right] \\
& - p_{I=0,J=0} E\left[U'(\tilde{\Pi})K(1+r)|\, z = h^\star, I = 0, J = 0\right],
\end{aligned}$$

where $p_{I=1,J=1}, p_{I=1,J=0}, p_{I=0,J=1}$ and $p_{I=0,J=0}$ denote the unconditional probabilities for the corresponding events.

Division of the right hand side of equation (28) by $U'(\Pi|z = h^\star, I = 0) = U'(\Pi|z = h^\star, I = 1, J = 0)$, which is a non-random scalar, leads to the following expression:

$$
\begin{aligned}
&-p_{I=1,J=1}E\left[(U'(\tilde{\Pi})/U'(\Pi|z = h^\star, I = 0))K(1+r)|\, z = h^\star, I = 1, J = 1\right] \\
&+p_{I=1,J=0}E\left[\max[(F - \tilde{P}), 0] - K(1+r)|\, z = h^\star, I = 1, J = 0\right] && (29)\\
&-p_{I=0,J=1}E\left[K(1+r)|\, z = h^\star, I = 0, J = 1\right] && (30)\\
&-p_{I=0,J=0}E\left[K(1+r)|\, z = h^\star, I = 0, J = 0\right] && (31)
\end{aligned}
$$

Since the marginal utility is generally lowest if the forward contract does not default ($I = 0$), the following inequality holds:

$$
\begin{aligned}
&-p_{I=1,J=1}E\left[(U'(\tilde{\Pi})/U'(\Pi|z = h^\star, I = 0))\, K(1+r)|\, z = h^\star, I = 1, J = 1\right] \\
< \;&-p_{I=1,J=1}E\left[K(1+r)|\, z = h^\star,\ I = 1,\ J = 1\right] && (32)
\end{aligned}
$$

The expressions (29), (30), (31) and the expression on the right hand side of inequality (32) sum up to the following unconditional expectation:

$$
E\left[\tilde{I}(1 - \tilde{J})\max[(F - \tilde{P}), 0] - K(1+r)\right]. \tag{33}
$$

Under the assumption that credit derivatives earn zero expected profits, the above expectation (33) is zero. Therefore, it has been shown that the following inequality holds:

$$
\frac{E\left[U'(\tilde{\Pi})\left[\tilde{I}(1 - \tilde{J})\max[(F - \tilde{P}), 0] - K(1+r)\right]|\, z = h^\star\right]}{U'(\Pi|\, z = h^\star,\ I = 0)} < 0.
$$

Since marginal utility is positive, this result implies that inequality (27) also holds.

The first part of the proposition also follows from the above argument. One has just to consider that in the case with default-free forward contracts inequality (32) becomes an equality. Therefore inequality (27) also holds as an equality, i.e., the necessary condition for an optimal solution, which is also a sufficient condition under our assumptions, is fulfilled.

It remains to show that $z^\star/h^\star$ is strictly greater than zero if credit derivatives are subject to default. Based on the first order condition, a strictly positive position in credit derivatives is optimal if the following inequality holds:

$$E\left[U'(\tilde{\Pi})\left[\tilde{I}(1-\tilde{J})\max[(F-\tilde{P}),0]-K(1+r)\right]|\,z=0\right]>0. \tag{34}$$

The left hand side of equation (34) can be rewritten as follows:

$$\begin{aligned}
& E\left[U'(\tilde{\Pi})\left[\tilde{I}(1-\tilde{J})\max[(F-\tilde{P}),0]-K(1+r)\right]|\,z=0\right] \\
= \; & E\left[E\left[U'(\tilde{\Pi})\left[\tilde{I}(1-\tilde{J})\max[(F-\tilde{P}),0]-K(1+r)\right]|\,z=0\right]|\,\tilde{I},\tilde{J}\right] \\
= \; & -p_{I=1,J=1}E\left[U'(\tilde{\Pi})K(1+r)|\,z=0,I=1,J=1\right] \\
& +p_{I=1,J=0}E\left[U'(\tilde{\Pi})(\max[(F-\tilde{P}),0]-K(1+r))|\,z=0,I=1,J=0\right] \\
& -p_{I=0,J=1}E\left[U'(\tilde{\Pi})K(1+r)|\,z=0,I=0,J=1\right] \\
& -p_{I=0,J=0}E\left[U'(\tilde{\Pi})K(1+r)|\,z=0,I=0,J=0\right] \\
= \; & -p_{I=1,J=1}E\left[U'(\tilde{\Pi}|\,z=0,I=1,J=1)\right]K(1+r) \\
& +p_{I=1,J=0}E\left[U'(\tilde{\Pi}|\,z=0,I=1,J=0)\right]E\left[\max[(F-\tilde{P}),0]-K(1+r)|I=1,J=0\right] \\
& +p_{I=1,J=0}Cov\left[U'(\tilde{\Pi}),\max[(F-\tilde{P}),0]-K(1+r)|\,z=0,\;I=1,\;J=0\right] \\
& -p_{I=0,J=1}E\left[U'(\tilde{\Pi}|\,z=0,I=0,J=1)\right]K(1+r) \\
& -p_{I=0,J=0}E\left[U'(\tilde{\Pi}|\,z=0,I=0,J=0)\right]K(1+r) \\
= \; & E\left[U'(\tilde{\Pi}|\,z=0)\right]E\left[\tilde{I}(1-\tilde{J})\max[(F-\tilde{P}),0]-K(1+r)\right] \\
& +p_{I=1,J=0}Cov\left[U'(\tilde{\Pi}),\max[(F-\tilde{P}),0]-K(1+r)|\,z=0,\;I=1,\;J=0\right] \\
= \; & p_{I=1,J=0}Cov\left[U'(\tilde{\Pi}),\max[(F-\tilde{P}),0]-K(1+r)|\,z=0,\;I=1,\;J=0\right],
\end{aligned} \tag{35}$$

where the last equality follows from the assumption that credit derivatives earn zero expected profits, i.e., $E\left[\tilde{I}(1-\tilde{J})\max[(F-\tilde{P}),0]-K(1+r)\right]=0$.

Thus, inequality (34) holds if the covariance term on the right hand side of equation (35) is positive. The positive sign of the conditional covariance can be seen as follows: If the forward defaults and no credit derivatives are held, the firm´s profit depends only on one random variable, $\tilde{P}$. Profit is an increasing function of P and strictly increasing for $P<F$. The payoff of a long position in credit derivatives is decreasing with P, and strictly decreasing for $P<F$. Since the marginal utility is itself a strictly decreasing function of the firm´s profit, it must be positively correlated with the payoff of the credit derivative. □

Proof of Proposition 6:

It can be shown by the same arguments used in the second step of the proof of proposition 1 that a negative value of $h^\star$ contradicts the assumption of zero expected profits of forward contracts. Thus, assume that $h^\star \geq 0$ and concentrate on a region where the objective function is strictly concave in h.

The optimal hedge ratio $h^\star/Q^\star$ is greater than one if the first derivative of the objective function with respect to h, evaluated at $h = Q^\star$, is greater than zero, i.e.,

$$E\left[U'(\tilde{\Pi})\left[(F-\tilde{P}) - \tilde{I}(1-\tilde{R})\max[(F-\tilde{P}),0]\right] | \, h = Q^\star\right] > 0. \tag{36}$$

To show that inequality (36) holds, rewrite the the left hand side of the inequality as follows:

$$\begin{aligned}
& E\left[U'(\tilde{\Pi})\left[(F-\tilde{P}) - \tilde{I}(1-\tilde{R})\max[(F-\tilde{P}),0]\right] | \, h = Q^\star\right] \\
= \; & E\left[E\left[U'(\tilde{\Pi})\left[(F-\tilde{P}) - \tilde{I}(1-\tilde{R})\max[(F-\tilde{P}),0]\right] | \, h = Q^\star\right] | \, \tilde{I}\right] \\
= \; & p\,E\left[U'(\tilde{\Pi})\left[(F-\tilde{P}) - (1-\tilde{R})\max[(F-\tilde{P}),0]\right] | \, h = Q^\star, \, I = 1\right] \\
& +(1-p)\,E\left[U'(\tilde{\Pi})(F-\tilde{P}) | \, h = Q^\star, \, I = 0\right] \\
= \; & p\,E\left[U'(\tilde{\Pi})\left[(F-\tilde{P}) - \max[(F-\tilde{P}),0]\right] | \, h = Q^\star, \, I = 1\right] \\
& +p\,E\left[U'(\tilde{\Pi})\tilde{R}\max[(F-\tilde{P}),0] | \, h = Q^\star, \, I = 1\right] \\
& +(1-p)\,E\left[U'(\tilde{\Pi})(F-\tilde{P}) | \, h = Q^\star, \, I = 0\right].
\end{aligned} \tag{37}$$

Now divide the right hand side of equation (37) by $U'(\Pi | \, h = Q^\star, \, I = 0)$, which is a non-random scalar. As a consequence, the marginal utility cancels from the first and third expectations. With respect to the first expectation, the same reasoning as in the proof of proposition 1 applies. After division, the sum on the right hand side of equation (37) becomes

$$\begin{aligned}
& p\,E\left[(F-\tilde{P}) - \max[(F-\tilde{P}),0] | \, I = 1\right] \\
+ & p\,E\left[(U'(\tilde{\Pi})/U'(\Pi | \, h = Q^\star, \, I = 0))\tilde{R}\max[(F-\tilde{P}),0] | \, h = Q^\star, \, I = 1\right] \\
& +(1-p)\,E\left[(F-\tilde{P}) | \, I = 0\right].
\end{aligned} \tag{38}$$

For the next step, note that the following inequality (39) holds:

$$E\left[(U'(\tilde{\Pi})/U'(\Pi|\,h=Q^\star,\,I=0))\tilde{R}\max[(F-\tilde{P}),0]|\,h=Q^\star,\,I=1\right] \;>\; E\left[\tilde{R}\max[(F-\tilde{P}),0]|\,h=Q^\star,\,I=1\right] \tag{39}$$

The reason is that the random variable $U'(\tilde{\Pi}|\,h=Q^\star,\,I=1)/U'(\Pi|\,h=Q^\star,\,I=0)$ takes values that are strictly greater than one if $P<F$.

Inequality (39) implies that

$$\begin{aligned}
&p\,E\left[(F-\tilde{P})-\max[(F-\tilde{P}),0]|\,I=1\right] \\
&+p\,E\left[(U'(\tilde{\Pi})/U'(\Pi|\,h=Q^\star,\,I=0))\tilde{R}\max[(F-\tilde{P}),0]|\,h=Q^\star,\,I=1\right] \\
&+(1-p)\,E\left[(F-\tilde{P})|\,I=0\right] \;>\; \\
&p\,E\left[(F-\tilde{P})-\max[(F-\tilde{P}),0]|\,I=1\right] \\
&+p\,E\left[\tilde{R}\max[(F-\tilde{P}),0]|\,I=1\right] \\
&+(1-p)\,E\left[(F-\tilde{P})|\,I=0\right] \;=\; \\
&E\left[(F-\tilde{P})-\tilde{I}\,(1-\tilde{R})\,\max[(F-\tilde{P}),0]\right]
\end{aligned}$$

Since expected profits of short positions in forwards are assumed to be zero, i.e., $E\left[(F-\tilde{P})-\tilde{I}\,(1-\tilde{R})\,\max[(F-\tilde{P}),0]\right]=0$, it has been shown that the following inequality (40) holds:

$$\frac{E\left[U'(\tilde{\Pi})\left[(F-\tilde{P})-\tilde{I}(1-\tilde{R})\max[(F-\tilde{P}),0]\right]|\,h=Q^\star\right]}{U'(\Pi|\,h=Q^\star,\,I=0)} > 0. \tag{40}$$

Because marginal utility is positive, inequality (40) implies that inequality (36) also holds. □

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