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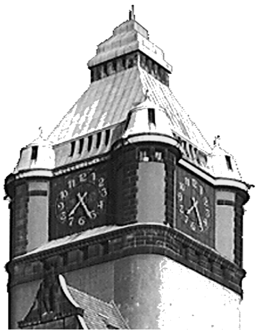

The impact of inflation risk on forward trading and production

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The impact of inflation risk on forward trading and production

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Abstract:

This note examines the behavior of a competitive firm that faces joint price and inflation risk. Given that the price risk is negatively correlated with the inflation risk in the sense of expectation dependence, the firm optimally opts for an over-hedge if the firm's coefficient of relative risk aversion is everywhere no greater than unity. Furthermore, banning the firm from forward trading may induce the firm to produce more or less, depending on whether the price risk premium is positive or negative, respectively. While the price risk premium is unambiguously negative in the absence of the inflation risk, it is not the case when the inflation risk prevails. In contrast to the conventional wisdom, forward hedging needs not always promote production should firms take in inflation seriously.

JEL-Classification: D21; D24;D81

Keywords: Forward markets; Expectation dependence; Inflation risk; Production

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1 Introduction

The importance of risk management has inspired empirical and theoretical contributions to investment, production and consumption decision making under uncertainty. Most of the literature on economic risk and risk behavior dealing with production and hedging decisions has incorporated the assumption that firms are concerned about random nominal wealth denominated in one currency. However, the firms final wealth may also change due to an unexpected inflation. Therefore, the economic analysis about risk management and production should be imbedded in a framework of inflation risk.

In some of the theoretical and empirical studies about the impact of inflation risk on the firm's behavior it is shown that the celebrated separation theorem holds under the joint price and inflation risk (see Battermann and Broll 2001, Adam-Müller 2002a,b). The study shows further that banning the firm from forward trading may induce the firm to produce more, a striking result that does not arise if there is no inflation risk.

The purposes of this study are to complement results from the literature, in particular Adam-Müller (2002a,b). To determine the firm's optimal forward position, the concept of expectation dependence (ED) *à la* Wright (1987) is proven to be useful (see also Wong 2012, 2013). While current the hedging literature specifies the inflation risk as a monotonically decreasing function of the price risk plus noise, expectation dependence provides much more general bivariate dependence structure. Given that the price risk is negatively correlated with the inflation risk in the sense of expectation dependence, this note shows that the firm optimally opts for an over-hedge (under-hedge) should the firm's coefficient of relative risk aversion be everywhere no greater (smaller) than unity, which is consistent with the results in the literature. Our study shows further that the firm optimally produces more or less in the absence than in the presence of forward hedging, depending on whether the price risk premium is positive or negative, respectively. In the absence of the inflation risk, the price risk premium is always negative, thereby rendering the adverse effect on output when forward trading is not allowed (Holthausen 1979). When the inflation risk prevails, the price risk premium can be positive so that forward trading may not promote production in contrast to the conventional wisdom.

The rest of this paper is organized as follows. Section 2 delineates the model of the competitive risk averse firm under price and inflation risk. Section 3 solves the model and provides insights for the impact of inflation risk on hedging and production. To determine the firm's optimal forward trading, the concept of expectation dependence is employed. The final section concludes.

2 The model

Consider a competitive firm that operates for one period with two dates, 0 and 1. To begin, the firm acquires inputs at known nominal prices to produce a single commodity. The nominal value of inputs at date 1 gives rise to a deterministic cost function, $C(Q)$, where $Q \geq 0$ is the output level chosen by the firm at date 0, $C(0) = C'(0) = 0$, and $C'(Q) > 0$ and $C''(Q) > 0$ for all $Q > 0$.[1]

At date 1, the firm sells its entire output, Q, at the uncertain nominal output price, $\tilde{P}$. The firm can hedge against this price risk, $\tilde{P}$, by selling (purchasing if negative) X units of its output forward at the known forward price, P^f, at date 0. Inflation risk is modeled by a stochastic purchasing power index, $\tilde{Z}$, with unit mean so that $\tilde{Z} - 1$ gauges surprises due to purchasing power changes. The inflation risk, $\tilde{Z}$, is neither hedgeable nor insurable. The firm's real income at date 1 is, therefore, given by

$$\tilde{\Pi} = \tilde{Z}[W + \tilde{P}Q + (P^f - \tilde{P})X - C(Q)], \tag{1}$$

where $W > 0$ is a fixed component of nominal income.

[1]The strict convexity of $C(Q)$ is driven by the firm's production technology that exhibits decreasing returns to scale.

Let $F(P)$ be the marginal cumulative distribution function (CDF) of $\tilde{P}$ over support $[\underline{P}, \overline{P}]$ with $0 < \underline{P} < \overline{P}$. Likewise, let $G(Z)$ be the marginal CDF of $\tilde{Z}$ over support $[\underline{Z}, \overline{Z}]$ with $0 < \underline{Z} < \overline{Z}$. To allow the price risk, $\tilde{P}$, to be correlated with the inflation risk, $\tilde{Z}$, denote $H(P, Z)$ as their joint CDF over support $[\underline{P}, \overline{P}] \times [\underline{Z}, \overline{Z}]$. Define the following function:

$$\mathrm{ED}(\tilde{P}|Z) = \int_{\underline{P}}^{\overline{P}} \left[\frac{H(P, Z)}{G(Z)} - F(P) \right] \mathrm{d}P, \tag{2}$$

for all $Z \in [\underline{Z}, \overline{Z}]$. According to Wright (1987), $\tilde{P}$ is negatively (positively) expectation dependent on $\tilde{Z}$ if $\mathrm{ED}(\tilde{P}|Z) \leq (\geq)\ 0$ for all $Z \in [\underline{Z}, \overline{Z}]$, where the inequality is strict for some non-degenerate intervals. Wright (1987) shows that negative (positive) expectation dependence is a sufficient, but not necessary, condition for negative (positive) correlation. In the sequel only the case wherein $\tilde{P}$ and $\tilde{Z}$ are negatively expectation dependent is considered.[2]

The firm is risk averse and possesses a von Neumann-Morgenstern utility function, $U(\Pi)$, defined over its real income at date 1, Π, with $U'(\Pi) > 0$ and $U''(\Pi) < 0$ for all $\Pi > 0$. The firm's ex-ante decision problem at date 0 is to choose its output level, Q, and its forward position, X, so as to maximize the expected utility of its real income at date 1:

$$\max_{Q \geq 0, X} \ \mathrm{E}[U(\tilde{\Pi})], \tag{3}$$

where $\mathrm{E}(\cdot)$ is the expectation operator with respect to $H(P, Z)$, and $\tilde{\Pi}$ is given by Equation (1). The first-order conditions for program (3) are given by

$$\mathrm{E}\{U'(\tilde{\Pi}^*)\tilde{Z}[\tilde{P} - C'(Q^*)]\} = 0, \tag{4}$$

and

$$\mathrm{E}[U'(\tilde{\Pi}^*)\tilde{Z}(P^f - \tilde{P})] = 0, \tag{5}$$

where an asterisk (*) signifies an optimal level. The second-order conditions for program (3) are satisfied given that $U''(\Pi) < 0$ and $C''(Q) > 0$.

[2]The less likely case wherein $\tilde{P}$ and $\tilde{Z}$ are positively expectation dependent can be analogously analyzed.

3 The impact of inflation risk

We assume that the forward price is assumed to be unbiased so that $P^f = \mathrm{E}(\tilde{P})$.[3] The firm's optimal forward position, X^*, is said to be an over-hedge, a full-hedge, or an under-hedge, depending on whether X^* is greater than, equal to, or less than the optimal output level, Q^*, respectively.

3.1 Hedging decision

Using the covariance operator, $\mathrm{Cov}(\cdot,\cdot)$, with respect to $H(P,Z)$, Equation (5) can be written as[4]

$$\mathrm{Cov}[U'(\tilde{\Pi}^*)\tilde{Z},\tilde{P}] = 0, \tag{6}$$

since $P^f = \mathrm{E}(\tilde{P})$. Differentiating $\mathrm{E}[U(\tilde{\Pi})]$ with respect to X and evaluating the resulting derivative at $Q = X = Q^*$ yields

$$\frac{\partial \mathrm{E}[U(\tilde{\Pi})]}{\partial X}\bigg|_{Q=X=Q^*} = -\mathrm{Cov}\{U'[\Pi(\tilde{Z})]\tilde{Z},\tilde{P}\}, \tag{7}$$

where $\Pi(\tilde{Z}) = \tilde{Z}[W + \mathrm{E}(\tilde{P})Q^* - C(Q^*)]$. If the right-hand side of Equation (7) is positive (negative), it follows immediately from Equation (6) and the second-order conditions for program (3) that $X^* > (<)\ Q^*$.

Cuadras (2002) proves that $\mathrm{Cov}[\alpha(\tilde{P}),\beta(\tilde{Z})]$ can be written in terms of the CDFs, $F(P)$, $G(Z)$, and $H(P,Z)$, as follows:

$$\mathrm{Cov}[\alpha(\tilde{P}),\beta(\tilde{Z})] = \int_{\underline{P}}^{\overline{P}}\int_{\underline{Z}}^{\overline{Z}}[H(P,Z) - F(P)G(Z)]\ \mathrm{d}\alpha(P)\ \mathrm{d}\beta(Z), \tag{8}$$

[3] If $P^f > (<)\ \mathrm{E}(\tilde{P})$, the firm would have a pure speculative motive to sell (purchase) the forward contracts.

[4] For any two random variables, $\tilde{X}$ and $\tilde{Y}$, it is true that $\mathrm{Cov}(\tilde{X},\tilde{Y}) = \mathrm{E}(\tilde{X}\tilde{Y}) - \mathrm{E}(\tilde{X})\mathrm{E}(\tilde{Y})$.

where $\alpha(\cdot)$ and $\beta(\cdot)$ are functions of bounded variation. Using Equation (8) with $\alpha(\tilde{P}) = \tilde{P}$ and $\beta(\tilde{Z}) = U'[\Pi(\tilde{Z})]\tilde{Z}$, the right-hand side of Equation (7) can be written as

$$-\int_{\underline{P}}^{\overline{P}} \int_{\underline{Z}}^{\overline{Z}} [H(P,Z) - F(P)G(Z)]\{U'[\Pi(Z)] + U''[\Pi(Z)]\Pi(Z)\} \, \mathrm{d}P \, \mathrm{d}Z$$

$$= -\int_{\underline{Z}}^{\overline{Z}} \mathrm{ED}(\tilde{P}|Z)\{1 - R[\Pi(Z)]\}U'[\Pi(Z)]G(Z) \, \mathrm{d}Z, \tag{9}$$

where $\mathrm{ED}(\tilde{P}|Z)$ is defined in Equation (2), and $R(\Pi) = -\Pi U''(\Pi)/U'(\Pi)$ for all $\Pi > 0$ is the Arrow-Pratt measure of relative risk aversion. Since $\tilde{P}$ is negatively expectation dependent on $\tilde{Z}$, $\mathrm{ED}(\tilde{P}|Z) \leq 0$ for all $Z \in [\underline{Z}, \overline{Z}]$. The right-hand side of Equation (9) is positive (negative) if $R(\Pi) \leq (\geq)\ 1$ for all $\Pi > 0$, thereby invoking the following proposition.[5]

Proposition 1. Given that the price risk, $\tilde{P}$, is negatively expectation dependent on the inflation risk, $\tilde{Z}$, the competitive firm that can sell its output forward at the unbiased forward price, $P^f = \mathrm{E}(\tilde{P})$, optimally opts for an over-hedge (under-hedge), i.e., $X^* > (<)\ Q^*$, should the Arrow-Pratt measure of relative risk aversion, $R(\Pi) = -\Pi U''(\Pi)/U'(\Pi)$, be no greater (larger) than unity for all $\Pi > 0$.

Proposition 1 generalizes the results of the literature to the case of expectation dependence. The intuition for Proposition 1 is as follows. Equation (6) implies that the optimal forward position, X^*, is the one that makes the multiple of the firm's marginal utility, $U'(\tilde{\Pi}^*)$, and the inflation risk, $\tilde{Z}$, invariant to the price risk, $\tilde{P}$. Since $\tilde{P}$ and $\tilde{Z}$ are negatively correlated in the sense of expectation dependence, they are natural hedges against each other. Starting with a full-hedge, the firm has a cross-hedging incentive that reduces the firm's forward position. Rewrite Equation (1) with $P^f = \mathrm{E}(\tilde{P})$ as

$$\tilde{\Pi} = \tilde{Z}\{W + \mathrm{E}(\tilde{P})Q - C(Q) + [\tilde{P} - \mathrm{E}(\tilde{P})](Q - X)\}, \tag{10}$$

[5]If $R(\Pi) = 1$ for all $\Pi > 0$, i.e, the firm has a logarithmic utility function, the firm's optimal forward position is a full-hedge, i.e., $X^* = Q^*$.

It is evident from Equation (10) that an over-hedge decreases (increases) the firm's nominal income at date 1 as P increases (decreases), which is more likely when Z is lower (higher). Given risk aversion, the over-hedge is more effective in reducing the variability of $U'(\tilde{\Pi}^*)\tilde{Z}$. Since the elasticity of the firm's marginal utility is gauged by the Arrow-Pratt measure of relative risk aversion, $R(\Pi) = -\Pi U''(\Pi)/U'(\Pi)$, the firm's marginal utility is insensitive (sensitive) to the price risk if $R(\Pi)$ is small (large). The cross-hedging incentive is therefore stronger (weaker) if $R(\Pi)$ is small (large). Taking expectations on both sides of Equation (10) yields

$$\mathrm{E}(\tilde{\Pi}) = W + \mathrm{E}(\tilde{P})Q - C(Q) + \mathrm{Cov}(\tilde{P}, \tilde{Z})(Q - X). \tag{11}$$

As is evident from the last term on the right-hand side of Equation (11), an over-hedge increases the firm's expected real income at date 1 since $\mathrm{Cov}(\tilde{P}, \tilde{Z}) < 0$. This gives rise to a speculative incentive that induces the firm to opt for an over-hedge. This speculative incentive is stronger (weaker) if the firm is less (more) risk averse, which dominates (is dominated by) the cross-hedging incentive, thereby rendering the optimality of an over-hedge (under-hedge), if $R(\Pi) \leq (\geq)\ 1$ for all $\Pi > 0$.

3.2 Production decision

Substituting Eq. (5) with $P^f = \mathrm{E}(\tilde{P})$ into Eq. (4) yields $C'(Q^*) = \mathrm{E}(\tilde{P})$, which implies that the separation theorem holds under the joint price and inflation risk. If the firm cannot hedge against the price risk, i.e., $X \equiv 0$, the first-order condition for program (3) becomes

$$\mathrm{E}\Big\{U'\{\tilde{Z}[W + \tilde{P}Q^\circ - C(Q^\circ)]\}\tilde{Z}[\tilde{P} - C'(Q^\circ)]\Big\} = 0, \tag{12}$$

where Q° is the optimal output level when forward trading is not allowed. Differentiating $\mathrm{E}[U(\tilde{\Pi})]$ with respect to Q and evaluating the resulting derivative at $Q = Q^*$ and $X = 0$

yields

$$\left.\frac{\partial \mathrm{E}[U(\tilde{\Pi})]}{\partial Q}\right|_{Q=Q^*,X=0} = \mathrm{E}\Big\{U'\{\tilde{Z}[W+\tilde{P}Q^* - C(Q^*)]\}\tilde{Z}[\tilde{P}-\mathrm{E}(\tilde{P})]\Big\}, \tag{13}$$

since $C'(Q^*) = \mathrm{E}(\tilde{P})$. If the right-hand side of Equation (13) is negative (positive), it follows immediately from Equation (12) and the second-order conditions for program (3) that $Q^\circ < (>)\ Q^*$.

Differentiating $\mathrm{E}[U(\tilde{\Pi})]$ with respect to X and evaluating the resulting derivative at $Q = Q^*$ and $X = 0$ yields

$$\left.\frac{\partial \mathrm{E}[U(\tilde{\Pi})]}{\partial X}\right|_{Q=Q^*,X=0} = \mathrm{E}\Big\{U'\{\tilde{Z}[W+\tilde{P}Q^* - C(Q^*)]\}\tilde{Z}[\mathrm{E}(\tilde{P})-\tilde{P}]\Big\}. \tag{14}$$

If $X^* > (<)\ 0$, it follows from Equation (5) and the second-order conditions for program (3) that the right-hand side of Equation (14) is positive (negative). Equations (13) and (14) then imply that $Q^\circ < (>)\ Q^*$ if $X^* > (<)\ 0$, thereby invoking the following proposition.

Proposition 2. If the competitive firm optimally sells (purchases) its output forward, i.e., $X^* > (<)\ 0$, at the unbiased forward price, $P^f = \mathrm{E}(\tilde{P})$, under the joint price and inflation risk, banning the firm from forward trading induces the firm to lower (raise) its optimal output level, i.e., $Q^\circ < (>)\ Q^*$.

From Proposition 1, $X^* > Q^*$ if $R(\Pi) \leq 1$ for all $\Pi > 0$. In this case, $Q^\circ < Q^*$ since $X^* > 0$. On the other hand, $X^* < Q^*$ if $R(\Pi) \geq 1$ for all $\Pi > 0$. In this case, X^* can be positive or negative, and thus Q° can be smaller or greater than Q^*, respectively. These results are consistent with those of Adam-Müller (2002a,b).

To see the intuition for Proposition 2, recast Equation (12) as

$$C'(Q^\circ) = \mathrm{E}(\tilde{P}) + \frac{\mathrm{Cov}\Big\{U'\{\tilde{Z}[W+\tilde{P}Q^\circ - C(Q^\circ)]\}\tilde{Z}, \tilde{P}\Big\}}{\mathrm{E}\Big\{U'\{\tilde{Z}[W+\tilde{P}Q^\circ - C(Q^\circ)]\}\tilde{Z}\Big\}}. \tag{15}$$

Equation (15) states that the firm's optimal output level, Q°, is the one that equates the marginal cost of production, $C'(Q^\circ)$, to the certainty equivalent output price that takes the inflation risk and the firm's preferences into account. Indeed, the second term on the right-hand side of Equation (15) captures the price risk premium, which must be positive (negative) if the firm optimally sells (purchases) its output forward, i.e., $X^* > (<)\ 0$, at the unbiased forward price, $P^f = \mathrm{E}(\tilde{P})$, thereby implying that $Q^\circ < (>)\ Q^*$.

In the absence of the inflation risk, i.e., $\tilde{Z} \equiv 1$, the price risk premium is unambiguously negative since $U''(\Pi) < 0$. In this case, $X^* > 0$ and thus $Q^\circ < Q^*$, which is the well-known result of Holthausen (1979). When the inflation risk prevails, the price risk premium can be positive or negative. Since the elasticity of the firm's marginal utility is gauged by the Arrow-Pratt measure of relative risk aversion, $R(\Pi) = -\Pi U''(\Pi)/U'(\Pi)$, the firm's marginal utility is insensitive to the price risk if $R(\Pi)$ is small. In this case, the price risk premium is mainly driven by the covariance between $\tilde{P}$ and $\tilde{Z}$, which is negative. Hence, the firm optimally produces less if $R(\Pi) \leq 1$ for all $\Pi > 0$. To see that the price risk premium can be positive if $R(\Pi)$ is large, consider the case that $\tilde{Z} = 1/\tilde{P}$. The firm's real income at date 1 is then given by $Q^\circ + [W - C(Q^\circ)]/P$, which decreases (increases) as P increases (decreases). Given risk aversion, the firm's marginal utility is positively correlated with the price risk. The multiple of the firm's marginal utility and the inflation risk is also positively correlated with the price risk if $R(\Pi) \geq 1 + A(\Pi)Q^\circ$ for all $\Pi > 0$, where $A(\Pi) = -U''(\Pi)/U'(\Pi)$ is the Arrow-Pratt measure of absolute risk aversion. This gives rise to a positive price risk premium so that the firm optimally produces more when forward trading is banned.

4 Concluding remarks

This study examined the behavior of a competitive risk averse firm facing joint inflation and price risk. When price risk is negatively correlated with the inflation risk in the sense of expectation dependence, the firm optimally opts for an over-hedge if the firm's coefficient of relative risk aversion is everywhere no greater than unity. Furthermore it is shown that banning the firm from forward trading may induce the firm to produce more or less, depending on whether the price risk premium is positive or negative, respectively. While the price risk premium is unambiguously negative in the absence of the inflation risk, it is not the case when the inflation risk prevails. In addition this note demonstrates that forward hedging needs not always promote production should firms take inflation seriously.

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