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COMPARING THE EFFECTS OF NEUTRAL AND NON-NEUTRAL SHOCKS ON CORPORATE HEDGING STRATEGY: AN EMPIRICAL ANALYSIS

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Abstract: *This paper examines the impact of the mechanism linking a firm's internal funds to its return on investment on its optimal investment, debt, and hedging strategy. We compare two models of corporate hedging, namely the Investment Opportunity (IO) model and the Technical Change (TC) model, to show how they differ in their empirical implications. In the IO model, shocks to cash flow are assumed to be related to neutral (multiplicative) shocks to the investment return, whereas in the TC model, shocks to cash flow are linked to non-neutral (non-multiplicative) shocks to the investment technology. We obtain general solutions for hedging with both mechanisms, but as they do not allow for a precise identification of the effects of the relevant parameters on hedging, debt, and investment, we derive approximated analytical solutions for hedging to compare the two models. Our analysis shows that the optimal investment, debt, and hedging strategies can be strongly dependent on the mechanism linking a firm's internal funds to its return on investment. Moreover, the two models can be distinguished by observing the extent of hedging for equal values of the relevant parameters and the correlation between investment and debt in a period of technological change. Finally, we simulate the effects of a productivity shock on the two models to illustrate how they react to the same shock. Our findings suggest that the correlation between investment and debt is informative about the way the risk associated with the investment return is hedged through derivative financial instruments. Our study provides valuable insights for firms in determining their optimal hedging strategy, investment, and debt decisions under different mechanisms of corporate hedging.*

Keywords: corporate hedging, investment, debt, hedging strategy, neutral shocks, non-neutral shocks, productivity shock, derivative financial instruments.

INTRODUCTION

This work contributes to discussion on how optimal hedging strategy, investment and debt can be strongly affected by the mechanism linking the firm's internal sources of finance to its return on investment.

Hedging can affect the payoff of a risk-neutral firm to the extent that some market imperfections make the firm's payoff a concave function of some state contingent variable. The rationales for the concavity of the payoff function can be related to the firm's tax schedule (Smith et al., 1985), to the costs of financial distress (Smith et al., 1985; Shapiro et al., 1998), to agency costs (Stulz, 1990), to asymmetric information problems (Rebello, 1995; DeMarzo et al., 1995), to costly external finance (Froot et al., 1993), or to a combination of some of these factors (Leland, 1998). Most of the models on corporate hedging, however, do not derive the investment decisions of the firms and focus on the choice of the optimal capital structure only. A valuable exception is the contribution of Froot, Scharfstein, and Stein (1993), where both investment and capital structure are endogenously determined. In Froot, Scharfstein, and Stein (1993), a change in the internal funds is linked to a neutral (i.e. multiplicative) shock to the return on investment. However, one could assert that, in a context of

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technological innovations (and highly reversible and volatile investment), shocks to investment return are likely to be non neutral, whereas neutral shocks are more likely to represent changes in price or in demand, which leave the production technology unmodified.

The present work centres around the comparison between neutral and non neutral shocks and establishes that the correlation between investment and debt is informative about the way the risk associated to the investment return is hedged through derivative financial instruments. To simplify the interpretation, neutral shocks are considered as changes in demand for output, and non neutral shocks as technological changes. By working through the framework by Froot, Scharfstein, and Stein (1993) of hedging with costly external finance, two models of hedging are compared: in the first one (here called Investment Opportunity, IO), shocks to the cash flow are assumed to be related to neutral (multiplicative) shocks to the investment return, whereas in the second one (here called Technical Change, TC), shocks to the cash flow are assumed to be linked to non neutral (non multiplicative) shocks to the investment technology. General solutions for hedging with both mechanisms are obtained in non closed-form. However, as the non closed-form solutions do not allow for a precise identification of the effects of the relevant parameters on hedging, debt and investment, the two models, IO and TC, are compared in the light of their empirical implications by using approximated analytical solutions.

The two mechanisms are presented, first, in the general formulation ending up with non closedform solutions (section 2), then in the approximated formulation, where analytical solutions for hedging are obtained (section 3). Subsequently, the two mechanisms are compared by deriving the effects of hedging on investment and debt and by illustrating how IO and TC models may react to the same productivity shock (section 4). Section 5 concludes.

Two Alternative Hedging Mechanisms

This section sets out to demonstrate that the correlation between investment and debt is informative about the way the risk associated to the investment return is hedged through derivative financial instruments.

The literature on corporate investment has mainly analysed the correlation between investment and cash flow, since Fazzari, Hubbard and Petersen (1988) argued that firms that are more financially constrained have a higher sensitivity of investment to cash flow. While the earlier contributions focused on the way the financial constraints should be properly captured (among others, Hoshi et al., 1991, Gertler et al., 1994, Lamont, 1997, Kaplan et al., 1997), subsequent empirical studies have examined the relationship between investment and cash flow in connection with hedging through financial derivatives. This trend has originated from the theoretical work of Froot, Scharfstein and Stein (1993), which suggests that the use of derivatives is able to modify the relationship between investment and cash flow of financially constrained companies significantly. In this respect, Allayannis and Mozumdar (2001) find that the investment-cash flow sensitivity is reduced when firms use derivative financial instruments, and Minton and Schrandt (1999) find that investment spending is negatively affected by the volatility of the cash flow. While Adam (2002) finds that corporate hedging increases the probability that a firm finances its investment through internally generated funds, Disatnik, Duchin and Schmidt (2014) find that corporate hedging facilitates greater reliance on external liquidity in lieu of internal resources.

The studies mentioned, however, pay little attention to the consideration that hedging against cash flow fluctuations may be a solution to different alternative hedging strategies: a company may decide to reduce cash flow fluctuations in order to hedge indirectly against different sources of shock

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affecting the return on investment, on condition that they are correlated to the internally generated funds. However, simply observing the investment-cash flow sensitivity is not informative about which strategy is actually adopted and which risks are actually hedged.

To demonstrate this statement and overcome the aforementioned limitation of the earlier research, this section works through the framework of Froot, Scharfstein, and Stein (1993) and presents the two models, Investment Opportunity (IO) and Technical Change (TC), each one describing the behaviour of a firm that chooses its risk management program in order to better coordinate its investing and financing policies. While the setup is the same, the two models are different in their assumptions about the mechanism linking the cash flow with the return on investment. As we shall see, the corporate risk profile can be inferred by examining how the use of derivative financial instruments modifies the correlation between investment in new technology and debt issued.

Consider the example of two European companies, IO and TC. The IO company is an exporter selling 75% of its product in US dollars to customers located abroad, whereas the TC companies is a producer importing 75% of its productive inputs (qualified workers and machinery) in US dollars from abroad. From the ordinary trading activity, the IO company has receivables in US dollars in six months' time, whereas the TC companies has commitments payable in US dollars in six months' time. Both firms are exposed to changes in the rate of exchange for the Euro against the US dollar. As this transactional risk is peripheral to the core business, the firms may want to decide fully to hedge against it.

Suppose now that the core business of both companies is also exposed to the foreign exchange risk.[1] For example, for a given level of investment expenditure in Euros, the demand for the IO product (thus the revenue on its investment) is exposed to the exchange rate risk, as exports rise when the Euro falls against the US dollar. The shock to the investment function of the IO company can be defined as neutral, to the extent that it leaves unchanged the technology choice and the factor productivity.[2] On the other hand, suppose that the TC firm is investing in research and development to improve the quality of its domestically sold product. For a given level of investment expenditure in Euros, when the Euro falls against the US dollar it can not longer import better quality researchers and machinery. This in turn may affect the productivity of the TC investment, which is thus exposed to the exchange rate risk. The shock to the investment function of the TC company can be defined as non neutral, to the extent that it affects the technology choice and the factor productivity.[3]Summarising, for both firms the return on investment (economic exposure) and the cash flow (transactional exposure) are exposed to the same hedgeable source of shock (currency risk), thus they are partially correlated. However, the nature of the economic exposure is technologically neutral (i.e. the shock is multiplicative) for the IO firm and non neutral (i.e. the shock is non-multiplicative) for the TC firm.

Both IO and TC models describe a risk-neutral firm that, first, decides its optimal hedging strategy at time 0, when both return on investment and internal funds available are uncertain, and, subsequently, decides the amount of investment and debt at time 1, when the random variable to be hedged is realised. Finally, at time 2, the production is realised and sold and the debt is repaid. The analytical

[1] Williamson (2001), for example, provides evidence on the correlation between the market value (i.e. core business) of multinational companies and exchange rates.

[2] Froot and Dabora (1999) find evidence that stock prices of "Siamese twin" companies are affected by the location of trade in different countries. Country effects, such as taxinduced investor heterogeneity, market-wide noise shocks and institutional inefficiencies may determine growth opportunity without necessarily affecting investment technology.

[3] Even though the recent literature has been challenged by the "productivity paradox", according to which information technology does not seem to be correlated to traditional total factor productivity measures, only a few studies deny a non neutral role of innovation in information technology. See Triplett (1999) for a survey.

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structure of the firm's maximisation problem is built on the following set of assumptions. Where it is not specified, the assumptions are common to both IO and TC models.

Marginal cost of debt

The marginal cost of debt is an increasing function of the amount given by a generic function C(D), where D is the amount of debt, C0(D) = CD > 0 and C00(D) = CDD > 0. The cost of debt, as FSS point out, can arise from different sources, such as the cost of bankruptcy and financial distress, informational asymmetry between lenders and borrowers, private benefits to managers from limiting their dependence on external investors. Firms carrying on investments with a highly uncertain outcome are likely to face particularly high borrowing costs as, first, lenders ask for higher risk premiums in order to finance riskier activities and, second, assets of high tech firms are highly intangible and cannot be used as reliable collateral. For simplicity, alternative sources of external finance are not considered.[4]

Random value of the internal funds

As the debt is increasingly costly, the firm gives priority to internal funds to finance its project of investment. Its budget constraint at time 1 is given by I = V + D, where V is the value of the internal funds available at time 1. Without any hedging policy, the value of the internal funds is given by V = V0ε, where V0 is the initial value at time 0 and ε is a hedgeable source of uncertainty, distributed as a Normal with mean 1 and variance σ2 and realised at time 1. The budget constraint of a non-hedging firm is thus given by

I = D + V0ε. (1)

In the above example of the IO and the TC companies, ε captures the change in the exchange rate for the Euro against the US dollar. By trading derivatives at time 0, the firm can modify the distribution of its cash flow across possible values of the shock ε. The decision to hedge is modelled under the following simplifying assumptions: (i) the fluctuations of the cash flow, V , are completely hedgeable without costs; (ii) hedging does not alter the expected value of the cash flow; (iii) hedging is linear, i.e. the sensitivity of the cash to the changes of the random variable is constant.

Assumption (i) is justifiable by arguing that the cost of hedging is virtually null, compared to the opportunity costs of holding hedging substitutes such as liquidity.[5] Assumption (ii) is a usual assumption of fair price of state contingent contracts. Assumption (iii) means that the usage of derivatives described in this model is limited only to forward and futures contracts, options contracts being ruled out. This simplification is justifiable to the extent that the purpose of these models is not to analyse what kinds of hedging instruments are optimal, but rather to what extent the firm should hedge against its risk exposure.[6] Internal funds after hedging are given by V = V0[h + (1 − h)ε], and the budget constraint becomes

I = D + V0[h + (1 − h)ε], (2)

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[4] Ruling out alternative sources of finance, such as new equity issues, can be justified by the empirical evidence, showing that "share issues typically account for less than 5% of total new external finance" (Whithed, 1992, p.1426), as well as by theoretical arguments, such as the cost advantage of credit over new equities (Fazzari et al.,1988; Bernanke et al., 1988) or equity rationing (Greenwald et al., 1988). See also Stiglitz (1987), Gertler (1988), Delli Gatti and Gallegati (2000) for a survey.

[5] See for example Smith and Stulz (1985), Stulz (1990), Nance, Smith, and Smithson (1993), Leland (1998).

[6] Some survey evidence also reports that non financial hedging firms use a substantial percentage of linear hedging instruments, equivalent in UK to 56% of foreign exchange derivatives and 38% of all types of derivatives (Mallin et al., 2000).

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where the value of h is determined at time 0 as a solution of the maximisation problem. In the special case of full hedging, where h = 1, the distribution collapses to the mean, and the value of the existing assets becomes nonstochastic: V = V0.

Return on investment

Different assumptions about the shock to the investment function characterise the two models, IO and TC, as follows.

IO investment function. The net present value of investment expenditure is given by

F(I) = θf(I) − I, (3)

where I is the investment, f(I) is the expected revenue of the output, with f0(I) = fI> 0 and f00(I) = fII< 0. θ is a multiplicative shock to the expected outcome of the investment decision.

TC investment function. The net present value of investment expenditure is given by

F(I,γ) = f(I,γ) − I, (4)

where, as before, fI> 0 and fII< 0. γ is a non-multiplicative shock to the expected outcome of the investment decision.

The shock to the investment function is neutral for the IO model (θ), non neutral for the TC one (γ). Recalling the different nature of the shocks occurring to the investment functions, one can think that the IO company is hit by a shock to the demand for its final product, whereas the TC company is hit by a shock to the elasticity of the final product to the investment expenditure. Therefore, the variable θ incorporates the randomness of the investment opportunities in the first model (IO), whereas the variable γ incorporates the randomness of the production technology in the second one (TC).[7]

Relation between return on investment and internal funds

Both IO and TC types of shock (θ and γ) are related to the internal funds according to a coefficient αj, with j = θ,γ.

IO shocks relation. The neutral shock to the investment function, θ, is given by θ = αθ(ε− 1) + 1. (5)

TC shocks relation. The non-neutral shock to the investment function, γ, is given by γ = αγ(ε− 1) + β. (6)

In the IO model, θ represents a neutral shock to the investment function, thus its expected level at time 0 is equal to 1 by construction. In the TC model, γ represents a non neutral shock to the investment function, hence, its expected value at time 0 is equal to the expected value of some parameter of the investment function. For example, if γ represents the elasticity of the investment function, its expected value, β, will be equal to the expected value of the investment elasticity.

The firms maximise their profit function given by the difference between the net revenues to the investment and the full repayment of debt, i.e. π = F(I)−C(D). The general optimal hedging solutions are given, respectively, by

$$h^*_{IO} = 1 + \frac{\alpha_\theta}{V_0}\frac{E_0\left[\frac{-f_I C_{DD}}{\theta f_{II} - C_{DD}}\right]}{E_0\left[\frac{-\theta f_{II} C_{DD}}{(\theta f_{II} - C_{DD})}\right]}, \qquad (7)$$

for the IO firm,[8] and by

[7] It should be remarked that it is not possible to interpret a non-multiplicative shock as anything other than a change in investment technology, neither is it possible to interpret a multiplicative shock as anything other than a change in value of the output sold. Different possible economic interpretations of the nature of the shocks, however, would not change the analytical structure and the empirical implications of the two mechanisms outlined.

[8] Froot, Scharfstein, and Stein (1993), p.1639, derive the IO solution (7) using a result by Rubinstein (1976).

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$$h^*_{TC} = 1 + \frac{E_0\left[\frac{-C_{DD}}{f_{II}-C_{DD}}\frac{\partial f_I}{\partial \varepsilon}\right]}{V_0 E_0\left[-\frac{f_{II}C_{DD}}{f_{II}-C_{DD}}\right]},$$ (8) for the TC firm.

Both optimal hedging strategies depend on the parameter αj (with j = θ,γ) expressing the relation between return on investment and internal funds. In equation (8), such an effect is captured by the expression $\frac{\partial f_I}{\partial \varepsilon}$, which includes αγ.[9]

Both IO and TC mechanisms imply that the best strategy is fully to hedge (h = 1) when there is no relation between return on investment and internal fund fluctuations (αj = 0). In the example mentioned in this section, αj = 0 corresponds to the special case in which a firm is exposed to transactional (peripheral) currency risk, but not to economic (core business) currency risk. In this case, both (7) and (8) confirm the intuition that the firm has an incentive completely to hedge the cash flow transactionalexposure: there is no reason to let the cash flow fluctuate if the fluctuations are unrelated to the firm's extra finance requirements arising from the core business activity.

The approximation

From the non closed-form solutions for hedging, (7) and (8),[10] little information can be extracted on the determinants of hedging and its effect on investment and debt, or on the difference between and the empirical implications of both mechanisms, IO and TC. This section develops approximated analytical solutions for optimal hedging to better compare the two alternative mechanisms.

The approximation consists in carrying out a second order Taylor expansion of the investment and cost functions, respectively, around the expected levels of the investment, I0, and the debt, D0, in order to obtain constant values of the second derivatives to be substituted in both solutions for hedging,
(7) and (8).[11]

The approximated expected revenue and cost functions defined above, i.e. f(I) and C(D), take the following quadratic forms:

$$f(I) \simeq \frac{a}{2}I^2 + bI + k,$$ (9)

with a = fII(I0) < 0, b = fI(I0) − I0fII(I0) > 0 and k = f(I0) − I0fI(I0) + 12I02fII(I0), where fI = aI + b, fII
= a;

$$C(D) \simeq \frac{c}{2}D^2 + rD + z,$$ (10)

with c = CDD(D0) > 0, r = CD(D0) − D0CDD(D0) > 0 and z = C(D0) − D0CD(D0) + 12D02CDD(D0), where CD = r + cD and CDD = c.

While the neutral multiplicative shock for the IO model is unchanged and given by (5), in this section the non neutral shock of the TC model is specified in terms of the parameters associated to investment elasticity of (9). To simplify the analysis, let the shock to the investment function in the TC model modify the marginal product of the investment function (i.e. b) leaving unchanged its concavity

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[9] In other words, the link between optimal hedging and the parameter α_j depends, in both solutions, on the sensitivity of the marginal return on investment to a change in the variable to be hedged (ε). However, while in the IO model such sensitivity is constant and simplifies to $\alpha_\theta f_I$, in the TC model $\frac{\partial f_I}{\partial \varepsilon}$ is not necessarily constant.

[10] They are implicit solutions because the ratio between expected values on the RHS of both expressions includes, firstly, the levels of the investment and the debt, both depending on ε and h_*, and secondly, a direct effect of ε on h_* through the shock to the investment function (either ϑ or γ).

[11] In Spanò (2001) the approximation method is evaluated in the light of numerical evidence by comparing non closed-form numerical simulations to the analytical approximation for the model by Froot, Scharfstein, and Stein (1993).

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calculated at I0 (i.e. a). Using the approximated investment function, (9), the shock to the marginal product is
$b = \alpha_b(\varepsilon - 1) + \mu$, (11)
where μ is the expected level of b and αb is the coefficient expressing the relation between productivity shock (b) and internal fund fluctuations (ε). Given expression (11), the sensitivity of the marginal return on investment to a change in the variable to be hedged, (which is a determinant of the hedging strategy in (8)), becomes

$$\frac{\partial f_I}{\partial \varepsilon} = \alpha_b . \qquad (12)$$

Expression (12) implies that, in the TC model, the direct (partial) effect of the hedgeable shock on the marginal product of the investment is constant and given by the coefficient αb.[12]
Using the approximated functions (9) and (10), the analytical solutions for the optimal hedging strategy become, respectively,

$$h_{IO} = 1 + \frac{\alpha_\theta}{V_0} \frac{\left(1 + r - cV_0 - \frac{bc}{a}\right)\left((a-c)^2 + 3a^2\alpha^2\sigma^2\right)}{(a-c)\left((a-c)^2 + 3ac\alpha^2\sigma^2\right)}, \qquad (13)$$

for the IO mechanism, and

$$h_{TC} = 1 + \frac{\alpha_b}{V_0 a}, \qquad (14)$$

for the TC mechanism.
The approximated analytical solutions (13) and (14) allow one directly to compute the optimal hedging strategy by using all virtually observable parameters, instead of considering the unobservable expectations of the non closed-form formulas for hedging, (7) and (8). The parameters involved in the optimal hedging determination are: the standard deviation of the hedgeable shock, σ; the level of internal funds available when the hedging decision is taken, V0; the parameters incorporating the characteristics of the investment and cost functions, a, b, c and r; and the coefficients linking the shock to the internal funds to the return on investment, αθ and αb, respectively, for the IO and the TC models.
The productivity shock expressed by (11) simplifies the solution for hedging in the TC model as, first, optimal hedging (hTC) appears to be linearly related to the coefficient linking internal funds and return on investment (αb) and, second, the variance of the hedgeable shock (σ) is a negligible determinant of the optimal hedging strategy around the expected equilibrium. These properties follow from the constant direct (partial) effect of the hedgeable shock on the marginal product of the investment, as expressed by (12). In the IO model, by contrast, the relation between hIO and the coefficient αθ is non-linear and the variance of the hedgeable variable is a non-negligible determinant of hedging.
Figure 1 reports the relationship, in both models, between the optimal hedging ratio and the value of the parameter linking return on investment and internal funds, αjwith j = θ,b. It illustrates an empirical implication derived from the approximated solutions for hedging, (13) and (14), which does not seem to be easily derivable from the general non closed-form solutions, i.e. that the TC firm is likely to hedge against its internal fund fluctuations in higher proportion than the IO firm. Optimal hedging strategy as function of the parameter capturing the relation between shock to
the internal funds

[12] Obviously, the overall effect of ε on the marginal product *fI* is not constant, as it depends also on the effect of the shock, ε, on the investment level, *I*.

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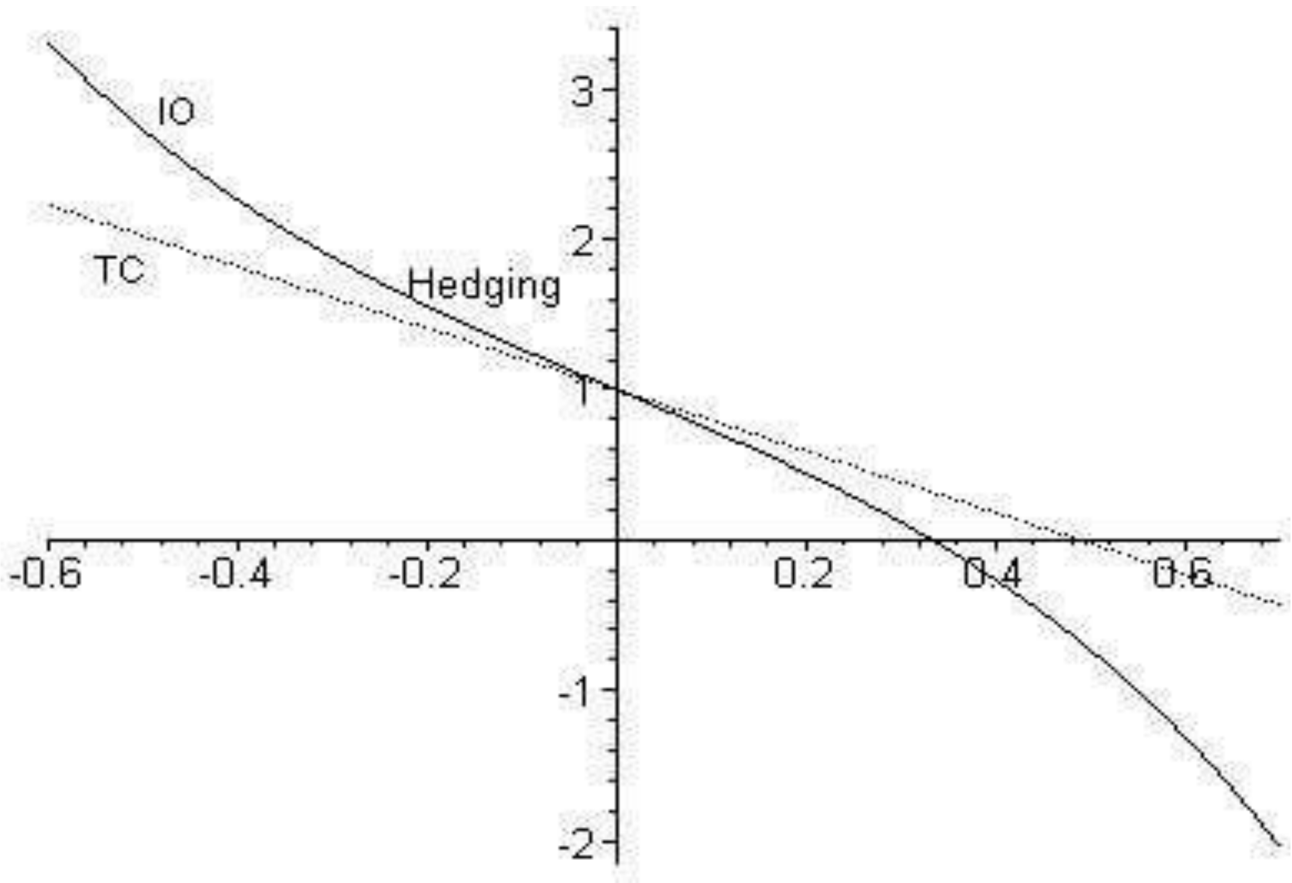

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and return on investment (α_j with $j=\theta,b$) in both IO and TC models. The continuous line refers to the IO optimal hedging strategy as a function of α_θ. The dotted line refers to the TC optimal hedging strategy as a function of α_b. The figure is based on the
approximated analytical solutions of both models of hedging.
The values of parameters of the approximated
investment and cost functions (a,b,k,c,r,z) are derived from the original function parameters, setting the elasticity of the output to the investment equal to 0.25; expected cash flow, investment and debt are, respectively, $V_0=10$, $I_0=20$, and $D_0=10$; the standard deviation of the shock ε to the internal funds is $\sigma=0.7$. Hedging equal to 0 indicates that the firm does not perform any hedging strategy; hedging equal to 1 indicates that the firm fully hedges against its internal fund fluctuations; hedging between 0 and 1 indicates that the firm adopts a strategy of partial reduction of internal fund risk exposure; negative hedging refers to a speculative strategy (increasing
internal fund risk Figure 1. Hedging in the IO and TC models exposure); hedging greater than 1 refers to an over-hedging strategy (reversing the sign of internal fund fluctuations).
This result follows from observing that, for equal values of the parameters in the IO and TC models, a higher link between return on investment and internal funds is needed in the TC model to move away from the full hedging ratio.
If $\alpha_j = 0$, the best strategy for both IO and TC firms is fully to hedge ($h_j = 1$) against cash flow fluctuations (transactional risk), as these are unrelated to the return on investment. If $\alpha_j > 0$, i.e. positive relation, the firm in both IO and TC models hedges only partially against its internal fund fluctuations ($0 < h_j < 1$), to provide an extra amount of internal funds to any extra amount of investment associated with it. For higher values of the parameter α_j the hedging strategy may collapse to zero ($h_j = 0$) or may become speculative ($h_j < 0$), in order to provide more internal funds to the investment, which is highly correlated with the hedgeable source of shock. Finally, if $\alpha_j < 0$, i.e. negative relation, the best strategy is to overhedge, in order to provide more cash flow when the return on investment is lower.

Effects of a productivity shock

To derive further empirical implications of the two models introduced in the previous sections, in this section the IO and TC mechanisms are compared by examining the effects of the same productivity shock on the investment and the debt in both models.
Suppose that both IO and TC firms experience a positive non neutral change in factor productivity, which is expressed by a shock to the parameter b of the approximated investment function,
(9).[13] In the IO model the shock to b is exogenous, i.e. unrelated to internal fund fluctuations, whereas in the TC model it is partially related to the hedgeable shock to the internal funds, ε, and determined according to (11). Following the example mentioned in section 2, such a productivity shock corresponds to the case in which both IO and TC European firms invest in research and development by acquiring machinery and qualified workers in US dollars. For the IO firm the investment in new technology is independent of the exchange rate, as inputs are paid in the same currency of the output (i.e. in US dollars), thus the exchange rate affects the final output only (demand for product) and not the inputs of the production (technology choice), the latter being idiosyncratic. The TC firm's

[13] Brynjolfsson and Hitt (1995) show that investment in information technology generated a competitive advantage at the level of individual firms and improved average returns of more than 50% between 1988 and 1992. Lehr and Lichtemberg (1998) find that investment in information technology has a positive impact on productivity in monopolistic and regulated industries.

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technology choice, by contrast, is heavily affected by the exchange rate, as the core business activity and the productive inputs are measured in different currencies, thus the firm finds it convenient to invest in new technology only when the Euro rises with respect to the US Dollar.

Using the approximated investment and cost functions, respectively, (9) and (10), the optimal investment and debt functions are given by

$$I^{IO}(\varepsilon) = \frac{\theta b - (1+r) + cV_0\varepsilon}{c - \theta a} \quad (15)$$

and

$$D^{IO}(\varepsilon) = \frac{\theta b - (1+r) + \theta a V_0\varepsilon}{c - \theta a}, \quad (16)$$

for the IO firm before hedging, and by

$$I_h^{IO}(\varepsilon) = \frac{\theta b - (1+r) + cV_0}{c - \theta a} + \frac{cV_0(1-\varepsilon)}{c - \theta a}(h_{IO} - 1) \quad (17)$$

and

$$D_h^{IO}(\varepsilon) = \frac{\theta b - (1+r) + \theta a V_0}{c - \theta a} + \frac{\theta a V_0(1-\varepsilon)}{c - \theta a}(h_{IO} - 1), \quad (18)$$

for the IO firm after hedging, where θ is the neutral shock to investment return, given by (5), and hIO is given by the hedging decision (13).

Similarly, the TC firm investment and debt functions are given, respectively, by

$$I^{TC}(\varepsilon) = \frac{1}{c-a}\left[\alpha_b(\varepsilon - 1) + \mu - (1+r) + cV_0\varepsilon\right] \quad (19)$$

and

$$D^{TC}(\varepsilon) = \frac{1}{c-a}\left[\alpha_b(\varepsilon - 1) + \mu - (1+r) + aV_0\varepsilon\right], \quad (20)$$

before hedging, and by

$$I_h^{TC}(\varepsilon) = -\frac{\alpha_b}{a}(\varepsilon - 1) + \frac{1}{c-a}\left[\mu - (1+r) + cV_0\right]$$

19 (21)

and

$$D_h^{TC} = \frac{1}{c-a}\left[\mu - (1+r) + aV_0\right], \quad (22)$$

After hedging, where μ is the expected marginal productivity of a unit of investment according to (11).

All expressions from (17) to (22) represent the optimal decisions (either to invest or to raise debt) as a function of the hedgeable shock to internal funds, ε.

While in both models investment and debt are related to the level of the internal funds (i.e. to ε), in the IO model the link goes through a neutral shock (θ) to the investment return (foreign demand for output) for a given technology, whereas in the TC model the link goes through a non neutral change in technology (b) for a given (domestic) demand for product.

Figure 2, computed using the above investment and debt functions for plausible values of the parameters, illustrates the effects of an equal positive change in productivity on investment and debt for both IO and TC firms, whether they are hedgers or non hedgers. The shift in the IO curves indicates that an exogenous change in productivity (b) occurs, which is not related to ε. The shift along the TC curves indicates that a change in productivity (b) occurs, which is partially related to ε (because

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in the TC model b is a function of ε, from (11)). The curves after hedging (Figures 2.b and 2.d) are flatter than the curves before hedging (Figures 2.a and 2.c), suggesting that the effect of hedging is to stabilise both investment and debt around their expected levels. The numerical specification adopted implies that hedging stabilises debt more than investment (debt curves are much flatter than investment curves after hedging). Moreover, the constant link between hedgeable shock and TC productivity shock, from (12), implies that the debt after hedging is fully stabilised in the TC model (see equation (22)).

From Figure 2, it can be observed that the optimal investment decisions, in both IO and TC mechanisms, change in the same direction as the productivity shock, the only difference between the two mechanisms being the extent of the variation (higher change in the optimal investment in the IO model than in TC after the shock to b). By contrast, optimal debt decisions in the IO and TC model have opposite sign reactions to the productivity shock: while in the IO model the debt level rises with the positive productivity shock, in the TC model the debt level either falls (Figure 2.c) or remains constant (Figure 2.d).

The different reactions to the productivity shock can be explained by considering how this is related to the internal funds. In the TC model, the investment in new technology is carried out when the internal funds rise (i.e. ε rises), which implies that either a lower or an equal amount of debt is needed to provide funds to it. In the IO model, the investment in new technology is idiosyncratic and unrelated to changes in the internal funds available, therefore, the firm needs to raise debt to provide funds to it.

Effects of the same positive productivity shock on investment and debt of both IO and TC firms. The arrows in all figures from 2.a to 2.c indicate the shifts following the productivity shock, starting from a common equilibrium. Figures 2.a and 2.c illustrate the reaction of both firms when they do not hedge against their internal fund fluctuations; figures 2.b and 2.c illustrate the reaction to the same shock when the firms do hedge. Figures 2.a and 2.b illustrate the investment functions, figures 2.c and 2.d illustrate the debt functions. The figures are based on the approximated analytical solutions of both models of hedging. All the parameters of investment and cost functions (a,b,k,c,r,z) from equations (9) and (10) are calibrated to respect the following criteria: (i) the expected value of the elasticity of the output to the investment is equal to 0.25, a value typically used in the Cobb-Douglas production function for the elasticity of the capital; (ii) the expected investment is greater than the expected internal funds available ($I0>V0$); (iii) the shock to b is the same in IO as in TC. Expected cash flow, investment and debt are set, respectively, to $V0=10$, $I0=20$, and $D0=10$. The standard deviation of the shock ε to the internal funds is $\sigma=0.7$. The parameter α is set equal to 0.2 for all $j=\theta$,b. The shock to b is calibrated as a change from 2.27 to 2.48. In response to the shock to b, the shock ε to the internal funds changes from 1 to 1.2 (x axis) in the TC model, whereas it remains unchanged at $\varepsilon=1$ in the IO model.

Table 1 summarises the different comovements of the variables implied by the same non neutral productivity shock as illustrated in Figure 2.

Table 1. Productivity shock effects: empirical implications

Synthesis of the empirical implications of the same positive productivity shock as inferred from Figure 2. The first column indicates all possible relations between investment (I) and debt (D). The second column reports the empirical implications of the IO model, where the shock to internal funds (ε) and the productivity shock (b) are not related. The third column reports the empirical implications of the TC model, where the shock to internal funds (ε) and the productivity shock (b) are positively related.

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	ε, b unrelated	ε, b positively related
I, D positively related	IO	
I, D negatively related		TC – no hedging
I, D unrelated		TC – hedging

The two alternative mechanisms lead to different empirical implications referring to periods of generalised technological change. In the IO mechanism, in which the productivity shock is not linked to the change in cash flow, investment and debt are positively related; in the TC mechanism, in which such a shock is linked to a change in cash flow, investment and debt are either negatively related, in the case of no hedging, or unrelated, in the case of hedging, the level of debt being fixed in the latter case. Therefore, comparing the two models allows us to conclude that financing and investment decisions, as well as the corporate hedging strategy, may be strongly affected by different mechanisms linking the internal funds to the return on investment.

Conclusion

The aim of this work has been to illustrate how optimal investment, debt, and hedging strategy may be strongly dependent on the mechanism linking the firm's internal funds to its return on investment. Two alternative models of corporate hedging have been derived from a setup of Froot, Scharfstein, and Stein (1993). The models are different for the mechanism linking the cash flow's fluctuations to a shock to the return on investment, the latter being neutral in the first model (Investment Opportunity - IO) and non neutral in the second one (Technical Change - TC). The neutral shock has been interpreted as a change to a firm's investment opportunity (analytically equivalent to a shock to the demand for output), whereas the non neutral shock has been interpreted as the consequence of a change in production technology. Optimal hedging decisions for both mechanisms have been obtained, first, in general non closed-form solutions (section 2), and then, by deriving approximated analytical solutions (section 3), which allow for a precise identification of the relationship between the hedging strategy and its determinants.

The approximated solution of the TC model has been derived under the simplifying assumption that the shock to the investment function is a pure shock to the marginal product of the investment, which does not affect the concavity of the investment function around the expected equilibrium. Under this assumption, it appears that, while in the IO model the variance of the hedgeable shock is a relevant determinant of the hedging strategy, in the TC model it is negligible, the optimal hedging around the expected equilibrium being determined by the concavity of the investment function and by the relation between internal funds and productivity shock. From the approximated solutions for hedging, the empirical implication follows that the TC firm is likely to hedge in higher proportion than the IO firm, as a stronger link between return on investment and internal funds is needed in the TC model to move away from the full hedging decision with respect to the IO model.

Finally, the same non neutral productivity shock has been considered in a numerical example to compare the two models, IO and TC (section 4). In the first mechanism (IO), where the productivity shock is not related to any change in the internal funds available (i.e. it is exogenous), investment and debt appear to be positively related; in the second one (TC), where such a shock is related to changes in the internal funds available (i.e. it is endogenous), investment and debt would be either negatively related, in the case of no hedging, or unrelated, in the case of hedging, the level of debt being fixed in the latter case. Therefore, in principle, the two different mechanisms linking internal funds and return

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on investment can be distinguished by observing corporate investment and debt in a period of technological innovations.

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