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## HOW DO BANKS RESPOND TO INCREASED FUNDING UNCERTAINTY?

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# How do banks respond to increased funding uncertainty?

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**Abstract**

This paper presents a simple model of risk-averse banks that face uncertainty over funding conditions in the money market. It shows when increased funding uncertainty causes interest rates on loans and deposits to rise, while bank lending and bank profitability fall. It also finds that funding uncertainty typically dampens the rate of pass-through from changes in the central bank's policy rate to market interest rates. These results help explain observed bank behaviour and reduced effectiveness of monetary policy in the 2007/9 financial crisis. Funding uncertainty also has strong implications for consumer welfare, and can turn deposits into a "loss leader" for banks.

*Keywords*: Bank lending, interbank market, interest rate pass-through, loan-to-deposit ratio, loan-deposit synergies, loss leader, monetary policy.

*JEL classifications*: E43 (interest rates), G01 (financial crises), G21 (banks).

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# 1 Introduction

Banks play a critical role in the economy as intermediaries that channel savings into higher-yielding investments. However, recent events in financial markets have made clear that our understanding of banks' behaviour as borrowers and lenders is far from complete. The financial crisis began in August 2007 with an extended period of turmoil in money markets, in which interest rates on term lending between banks disconnected from the Fed's target overnight rate. Taylor and Williams (2009) document how the federal funds rate as well as interest rates on term loans between banks (measured, for example, by Libor) diverged substantially from the central bank's policy rate and remained unusually volatile for an extended period of time. Moreover, these disruptions were not limited to the US, but occurred in financial markets around the world, including in the UK, the Eurozone, and Japan.

In this paper, I use a simple model to show how such heightened uncertainty over funding conditions in the money markets can help explain several diverse aspects of bank behaviour observed in the recent financial crisis. These include a reduction in bank lending, decreases in the size of banks' balance sheets, and increased competition for retail deposits. Moreover, the model predicts that higher funding uncertainty leads to a decline in bank profitability, and reduces the influence of monetary policy on equilibrium market interest rates on loans and deposits.

I consider a risk-averse commercial bank that makes loans to and takes deposits from its customers, and is also funded by equity capital and participation in the wholesale funding market.[1] The bank has a degree of market power in loan and deposit markets, while it acts as a price-taker in the money market.[2] The key feature of the model is that the interest rate at which the bank can borrow (or lend) in the wholesale market is uncertain. This may reflect recent dislocations in the money market, but, more generally, could also represent uncertainty over possible actions by the central bank that affect a bank's funding conditions.[3]

[1] In an influential paper, Froot and Stein (1998) argue that banks should be concerned with risk management as they in practice cannot frictionlessly hedge all the risks they face. There are many other reasons why banks may act as if they were risk-averse, including costs of financial distress, non-linear tax systems, and delegation of control to risk-averse managers; see also Greenwald and Stiglitz (1990). On the empirical side, Angelini (2000) shows how intra-day behaviour in the Italian interbank market is consistent with risk aversion, while, much earlier, Ratti (1980) finds evidence for risk-averse behaviour by US commercial banks.

[2] It is a standard assumption that banks are price-takers in the money market, see Hannan and Berger (1991), Klein (1971), Neumark and Sharpe (1992), Wong (1997), and others. This can be justified by noting that an individual bank may be too small to influence wholesale funding rates. A different strand of the literature focuses on the adverse impact of asymmetric information in the interbank market, see, e.g., Freixas and Holthausen (2005), Freixas and Jorge (2008), and Rochet and Tirole (1996).

[3] I do not attempt to explain what causes such uncertainty over funding conditions, but rather

I show that funding uncertainty leads to “risk synergies” between the loan and deposit sides of a bank: an increase, say, in a bank’s deposit base reduces the funding risk exposure of further loan commitments, which in turn makes loans themselves more attractive (Proposition 1). As uncertainty over funding conditions increases, these risk synergies become stronger, and the bank becomes more concerned with asset-liability management—that is, interactions between the two sides of its balance sheet.

An increase in funding uncertainty induces highly extended banks with high loan-to-deposit ratios to essentially reverse their prior strategy: they now cut back on their loan commitments, while at the same time trying to attract a stronger deposit base with higher interest rates (Proposition 2). This result is consistent with the behaviour of many banks in the financial crisis, including widespread reductions in leverage and shrinkage of balance sheets. In the UK, for example, banks such as Royal Bank of Scotland had high loan-to-deposit ratios at the outset of the financial crisis and were heavily dependent on wholesale funding, while, in response, they have now set themselves the aim of reducing their loan-to-deposit ratios to no more than 100%.

As the crisis unfolded in 2008, a large number of banks found themselves burning through their equity capital due to writedowns on risky loans and other securities, as well as trading losses (see, e.g., Brunnermeier, 2009). I show that such decreases in equity capital also induce banks to reduce their loan-to-deposit ratios, with equilibrium interest rates on loans and deposits both increasing (Proposition 3).[4] Taken together, Propositions 2 and 3 may help explain the empirical evidence that US banks sharply decreased lending in the financial crisis, but that banks with better access to deposit finance (higher deposit-to-asset ratios) cut their lending by less (Ivashina and Scharfstein, 2009).

Funding uncertainty also has surprisingly strong implications for bank profitability and consumer welfare in loan and deposit markets.[5] In particular, increased uncertainty over funding conditions reduces a bank’s expected profits, as measured, for example, by its average return on equity (Proposition 4). Moreover, loan-deposit synergies can lead to cross-subsidization where either its loans or deposits business

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focus on exploring its impact on bank behaviour. Taylor and Williams (2009) present empirical evidence that movements in (unsecured) interbank funding rates in the recent financial crisis can be explained by changing perceptions of counterparty risk amongst market participants.

[4]Amongst other things, this result is also consistent with empirical evidence that low-capital banks tend to charge higher interest rates on loans to their borrowers than well-capitalized banks, see, e.g., Hubbard, Kuttner and Palia (2002).

[5]In the absence of funding uncertainty (or with risk-neutrality), a bank’s market power implies that equilibrium features too few loans (for which the bank’s customers pay too much interest) and too few deposits (on which depositors receive too little interest).

becomes a "loss leader." For example, if the market for loans is very attractive relative to deposits, increased funding uncertainty may induce a bank to offer depositors an interest rate that exceeds its own (expected) funding rate. This implies that depositor welfare exceeds the level associated with a competitive market (Proposition 5). This risk-based version of loss leaders differs markedly from other mechanisms that have been identified in the industrial organization literature.[6]

Central banks around the world responded to the recent turmoil in financial markets by aggressively cutting interest rates. The degree to which such rate changes are passed on to market interest rates is a key factor in determining the impact of monetary policy on the real economy. However, many commentators expressed surprise at the apparently small impact that rate cuts had, especially across credit markets. I show that heightened funding uncertainty typically dampens the degree of pass-through from changes in the central bank's policy rate to equilibrium market interest rates for borrowers and depositors. This provides an explanation for why monetary policy may have been less effective at influencing bank behaviour, and why an assumption of full interest rate pass-through may be unsafe under conditions of money market turmoil.

In broad terms, these results resemble the emerging base of stylized facts on bank behaviour in the 2007/9 financial crisis, notably on reduced bank lending, increased competition for deposits, and reduced monetary policy effectiveness.[7] They are consistent with a view that the turmoil in money markets that began in the summer of 2007 played an important role in causing and prolonging the crisis. In banking systems with high loan-to-deposit ratios such as the UK, increased funding uncertainty tends to make the banks themselves, their shareholders and borrowers worse off, while depositors may end up benefitting substantially.

Section 2 sets up the benchmark model and Section 3 derives its equilibrium conditions. Sections 4 to 7 contain the main analysis and results. Section 8 shows that the key insights apply more generally in settings with multiple sources of risk and competition between banks with differentiated products in loan and deposit markets. Section 9 offers concluding comments.

[6]These generally rely on complementarities on the product side (e.g., razor and razor blades) or on particular features of the strategic interaction between firms. By contrast, in my model, loss leaders can occur even in a single-bank setting where loans and deposits are entirely independent in terms of demand and supply conditions (as well as operating costs).

[7]The finding that heightened funding uncertainty can account for such diverse aspects of bank behaviour distinguishes this explanation from others. For example, in a standard model, a decrease in the demand for loans also leads to a decline in bank lending and bank profitability. However, it is less clear how or why reduced loan demand simultaneously also increases deposit rates *and* dampens equilibrium interest rate pass-through. Funding uncertainty, by contrast, presents a simple mechanism that connects these different aspects of bank behaviour.

# 2 A simple model

I begin by considering a simple model of a single risk-averse bank that makes loans and takes deposits from its customers, and is also funded by equity capital and participation in the interbank market.[8]

The bank has a degree of market power in the loan and deposit markets, for example, due to product differentiation (perhaps at a regional level), certain regulatory restrictions, or because part of its customer base is "captive" due to informational lock-in or switching costs. In particular, the inverse demand curves for loans $L$ is given by $r_L = f_L(L)$, where $r_L$ is the market interest rate on loans, and demand is downward-sloping in that $f'_L(\cdot) < 0$. Similarly, the inverse supply curve for deposits $D$ is given by $r_D = f_D(D)$, where $r_D$ is the market interest rate on deposits, and higher deposit rates attract more depositors, so $f'_D(\cdot) > 0$.[9]

In addition to deposits, the bank's operations are funded by an (exogenous) amount of equity capital $K$ that is put up by its shareholders. It can also borrow or lend in the money market, where I adopt the notational convention that net borrowing is denoted by $M$ (so the bank is a net borrower if $M \geq 0$ and a net lender otherwise). The bank's balance sheet constraint is therefore given by

$$L = D + M + K, \tag{1}$$

where the bank's only assets are its loans, and its liabilities are comprised of deposits, net wholesale borrowing, as well as equity capital.

The key feature of the model is that the bank faces uncertainty over funding conditions in the money market. In particular, the bank acts as a price-taker in the wholesale market, but does not precisely know the funding rate $r$ when it makes decisions on its loans and deposits. Let $\bar{r}$ denote the expected funding rate and $\sigma_M^2$ denote the degree of funding uncertainty (that is, the variance of the funding rate).

To focus sharply on the impact of funding uncertainty and its implications for a bank's asset-liability management, I assume that there are no operational economies of scope between the loan and deposit sides of the bank. Without much further loss of generality, the bank's operating costs are normalized to zero. I also abstract from other institutional features such as deposit insurance and reserve requirements.

[8] Boyd and de Nicoló (2005), Hannan and Berger (1991), Klein (1971), Neumark and Sharpe (1992), Stein (1998), and Wong (1997) analyze related models of loan and/or deposit markets, although none of these papers consider the impact of funding uncertainty in the money market.

[9] See, e.g., Sharpe (1990) and Petersen and Rajan (1994) for theoretical and empirical support for informational lock-in as a source of banks' market power. Klemperer (1995) provides a general discussion of switching costs, and see, e.g., Kim, Kliger and Vale (2003) for empirical evidence of switching costs in banking.

All together, the bank's profit function is therefore given by

$$\Pi = r_L L - r_D D - rM, \tag{2}$$

reflecting the income from loans, interest payments on deposits, as well as interest payments (respectively, income) on the bank's interbank position if it is a net borrower (respectively, lender) in this market. Finally, the bank is risk-averse in that its concave utility function $U(\Pi)$ exhibits constant absolute risk aversion, with coefficient $\lambda \equiv -U''(\Pi)/U'(\Pi)$.

The timing of the model can be summarized as follows. At the beginning of the period, the bank commits to a volume of loans and deposits—both optimally chosen to maximize expected utility—based its available equity capital and expected funding conditions in the interbank market. Following this, the interbank rate is realized, and the bank pays or receives money depending on whether it is a net borrower or lender in the wholesale market. The bank's end-of-period payoffs from the loan, deposit and money markets determine its overall profits.[10]

At the beginning of the period, the bank therefore solves the following problem of maximizing expected utility subject to its balance sheet constraint:

$$\max_{L,D} E\left[U(\Pi)\right] \text{ subject to } M = L - D - K.$$

This problem turns out to be well-behaved under the assumption that the two second-order conditions for the underlying risk-neutral benchmark (where $\lambda = 0$) are satisfied, that is, $\Pi_{LL} < 0$ and $\Pi_{DD} < 0$.[11] Interior solutions for loans and deposits are guaranteed by $f_L(0) > \bar{r} > f_D(0)$ and $K \leq L$.[12] Note that $\Pi_{LD} = \Pi_{DL} = 0$ as there no operating synergies between the loan and deposit sides of the bank.[13]

[10] Given the one-period nature of the model, I cannot use it to address issues arising from differing maturities of a bank's assets and liabilities.

[11] The second-order conditions can be written in terms of the underlying demand and supply functions as $\Pi_{LL} = 2f_L'(L) + Lf_L''(L) < 0$ and $\Pi_{DD} = -2f_D'(D) - Df_D''(D) < 0$. In other words, loan demand is not too convex and deposit supply is not too concave. In the interest of generality, I leave the functional forms of $f_L(\cdot)$ and $f_D(\cdot)$ unspecified for now.

[12] The condition $K \leq L$ is sufficient to ensure that equilibrium deposits are non-negative. It is likely to be satisfied in practice since a bank's loan portfolio is generally many times larger than its capital base. (See also Section 6 for a linear example that brings out this condition.)

[13] The benchmark model assumes that the bank commits to quantities by choosing deposit and loan volumes to maximize expected utility. This makes interpreting the results particularly straightforward given that the bank's balance sheet constraint is also in terms of quantities. Alternatively, however, one can think of the bank choosing prices (that is, interest rates) on deposits and loans. It is easy to show that the two first-order conditions in this case are exactly equivalent to those from the benchmark model, so all the following results also apply.

# 3 Loan-deposit synergies

In this section, I derive the equilibrium conditions for the model, and use them to show that funding uncertainty naturally leads to "risk synergies" between the loan and deposit sides of a bank.

As a first step to solving the problem, plugging the balance sheet constraint into the bank's profit function and some rearranging yields

$$\Pi = (r_L - r)\, L + (r - r_D)\, D + rK. \tag{3}$$

The bank derives profits from three sources. First, it makes an interest margin of $(r_L - r)$ on the volume of its loan commitments $L$, reflecting loan rates in excess of wholesale funding costs. Second it makes an interest margin of $(r - r_D)$ on the volume of its deposit base $D$, reflecting deposit rates below its own funding costs. Third, it makes the interbank rate $r$ on its equity capital $K$, as equity implicitly relieves it from borrowing a corresponding amount in the wholesale market.

The two first-order conditions for the bank's problem are

$$E\left[U'(\Pi)\, \Pi_L\right] = 0 \text{ and } E\left[U'(\Pi)\, \Pi_D\right] = 0, \tag{4}$$

which simply states that the expected marginal utility both of additional loans and deposits must be zero in equilibrium. Since marginal utility is positive $U'(\Pi) > 0$, these conditions can also be written as

$$E\left[\Pi_L\right] + \frac{cov\left(U'(\Pi), \Pi_L\right)}{E\left[U'(\Pi)\right]} = 0 \text{ and } E\left[\Pi_D\right] + \frac{cov\left(U'(\Pi), \Pi_D\right)}{E\left[U'(\Pi)\right]} = 0. \tag{5}$$

In equilibrium, therefore, the expected marginal profit on loans $E\left[\Pi_L\right]$ equals the marginal risk from loans, $-cov\left(U'(\Pi), \Pi_L\right)/E\left[U'(\Pi)\right]$, and equivalently for deposits.[14]

To simplify these expressions, I use Taylor expansions (around expected profits $E[\Pi]$) for marginal risks, which yields $cov\left(U'(\Pi), \Pi_L\right)/E\left[U'(\Pi)\right] = -\lambda \cdot cov\left(\Pi, \Pi_L\right)$ on the loan side and $cov\left(U'(\Pi), \Pi_D\right)/E\left[U'(\Pi)\right] = -\lambda \cdot cov\left(\Pi, \Pi_D\right)$ for deposits. By Stein's lemma, these approximations are exact for the case where uncertainty on the funding rate is normally distributed, and, in general, they are reasonably accurate whenever uncertainty is not too large.[15]

[14] By definition, the risk premium $\mu$ satisfies $U(E[\Pi] - \mu) = E[U(\Pi)]$, so differentiating with respect to loans implies that $U'(E[\Pi] - \mu)\,(E[\Pi_L] - \partial\mu/\partial L) = 0$. Using that $E[XY] = E[X]E[Y] + cov(X, Y)$ for two random variables $X$ and $Y$ yields that the marginal risk from loans $\partial\mu/\partial L = -cov\left(U'(\Pi), \Pi_L\right)/E\left[U'(\Pi)\right]$ as claimed.

[15] Stein's lemma states that if two random variables $X$ and $Y$ are bivariate normally distributed and $g'(Y) < \infty$, then $cov(X, g(Y)) = E[g'(Y)] \cdot cov(X, Y)$. See, e.g., Huang and Litzenberger

The two first-order conditions for the bank's problem can thus be restated as

$$\Omega_L \equiv E[\Pi_L] - \lambda \cdot cov(\Pi, \Pi_L) = 0, \tag{6}$$

and

$$\Omega_D \equiv E[\Pi_D] - \lambda \cdot cov(\Pi, \Pi_D) = 0. \tag{7}$$

To interpret these equations, observe first that the marginal profit on loans $\Pi_L = f_L(L) + Lf_L'(L) - r$, so $\partial\Pi_L/\partial r < 0$. The reason is simply that a higher funding rate depresses the interest margin the bank makes on loans. By contrast, the marginal profit on deposits $\Pi_D = -f_D(D) - Df_D'(D) + r$, so $\partial\Pi_D/\partial r > 0$. From these arguments, it is clear that the *marginal* risks on loans and deposits move in opposite directions.

Now consider the initial formulation of the bank's profit function as $\Pi = r_L L - r_D D - rM$, and observe that $cov(\Pi, \Pi_L) = \sigma_M^2 M$ while $cov(\Pi, \Pi_D) = -\sigma_M^2 M$. Clearly, if the bank is a net borrower in the wholesale market (with $M > 0$), then a higher funding rate $r$ is bad news for its overall profits. Moreover, from the first-order conditions, this also implies that $E[\Pi_L] > 0$ and $E[\Pi_D] < 0$, so equilibrium loans are lower than under risk-neutrality (since $\Pi_{LL} < 0$), and, conversely, equilibrium deposits are higher (since $\Pi_{DD} < 0$).[16] The opposite conclusions hold if the bank is a net lender in the wholesale market, $M < 0$. Finally, if $M = 0$, then the bank's overall profit $\Pi$ remains unaffected by funding uncertainty—although decisions on loans and deposits remain interdependent at the margin.

To see this interdependence more formally, differentiating the first-order condition $\Omega_L = 0$ shows that

$$\frac{\partial L^*}{\partial D} = \frac{\Omega_{LD}}{-\Omega_{LL}}. \tag{8}$$

An increase in deposits decreases the marginal risk that the bank faces on its *loans* (and vice versa)

$$\Omega_{LD} = \Omega_{DL} = -\lambda \cdot cov(\Pi_D, \Pi_L) > 0, \tag{9}$$

since $\Pi_{LD} = \Pi_{DL} = 0$ (given no operating synergies) and $cov(\Pi_D, \Pi_L) = -\sigma_M^2$. The second-order conditions for loans

$$\Omega_{LL} = -\Pi_{LL} + \lambda \cdot var(\Pi_L) < 0, \tag{10}$$

(1988). To apply this result, note that if the funding rate $r$ is normally distributed, then the bank's profits $\Pi$ and marginal profits on loans $\Pi_L$ and deposits $\Pi_D$ are also all normally distributed.

[16] Observe also that, in expectation, the bank always makes a positive interest margin from providing financial intermediation since $E[\Pi_L] + E[\Pi_D] = [f_L(L) - f_D(D)] + Lf_L'(L) - Df_D'(D) = 0$, implying that $(r_L^* - r_D^*) > 0$ as $f_L'(\cdot) < 0$ and $f_D'(\cdot) > 0$. I discuss the impact of funding uncertainty on bank profitability in more detail in Section 6.

since $E[\Pi_{LL}] = \Pi_{LL} < 0$ and $var(\Pi_L) = \sigma_M^2$. Putting these together gives that

$$\frac{\partial L^*}{\partial D} = \frac{\lambda\sigma_M^2}{-\Pi_{LL} + \lambda\sigma_M^2}. \tag{11}$$

The same approach shows that the response of equilibrium deposits to an increase in loans can be written as

$$\frac{\partial D^*}{\partial L} = \frac{\lambda\sigma_M^2}{-\Pi_{DD} + \lambda\sigma_M^2} \tag{12}$$

since $E[\Pi_{DD}] = \Pi_{DD} < 0$ by the second-order condition and $var(\Pi_D) = \sigma_M^2$. As both cross effects lie within the unit circle (that is, $0 < \partial L^*/\partial D < 1$ and $0 < \partial D^*/\partial L < 1$), there is a unique and stable equilibrium in loans and deposits in what follows.

**Proposition 1** *In the presence of funding uncertainty $\sigma_M^2 > 0$, a bank has loan-deposit synergies in that $\partial L^*/\partial D > 0$ and $\partial D^*/\partial L > 0$.*

The intuition for the result is straightforward: all else equal, an increase in a bank's deposit base means that a further loan commitment leads to less borrowing in the money market, and thus also to less funding risk exposure, which in turn makes extending loans relatively more attractive. This provides a reason for why there are synergies to a bank conducting both loan and deposit activities under a single roof. Amongst other things, such risk benefits naturally give rise to a bank's concerns with asset-liability management. This contrasts sharply with similar models, e.g., Hannan and Berger (1991), Neumark and Sharpe (1992), in which loan and deposit decisions are entirely independent (often due to risk neutrality).[17]

Proposition 1 also offers a perspective on the observation that, at the height of the boom in the mid 2000s, banks funded most of the new loans from wholesale borrowing rather than increases in their deposit bases (*Financial Times*, 19 June 2009). The proportion of a small increase in a bank's loan commitments that is funded by way of increased money market exposure is given by

$$\frac{dM^*}{dL} \approx \left(1 - \frac{\partial D^*}{\partial L}\right) = \frac{-\Pi_{DD}}{-\Pi_{DD} + \lambda\sigma_M^2}. \tag{13}$$

So, if funding uncertainty was indeed negligible during the boom period (or also if risk aversion was very low), then $dM^*/dL \approx 1$ and it is entirely rational for a

[17]The independence of loans and deposits in the risk-neutral case is analogous to the classic separation of savings and investment decisions with perfect capital markets. See also Kashyap, Rajan and Stein (2002) for a related argument that a bank's role as a liquidity provider in the face of potential deposit withdrawals and drawdowns of loan commitments leads to synergies between its loan and deposit sides.

bank to fund an increase in loans almost solely by way of wholesale borrowing. However, if funding uncertainty becomes more important, as with the onset of the 2007/9 financial crisis, a bank relies more heavily on deposits for funding—precisely because of the higher risk synergies between the two sides of its balance sheet.[18]

# 4 Interbank market exposure

Building on these insights, I now explore the implications of funding uncertainty for banks' loans and deposit decisions and the corresponding interest rates. These also yield predictions on its impact on banks' funding exposure.

Recall that the bank's equilibrium choices of loans $L^*$ and deposits $D^*$ are determined by a system of two simultaneous equations, where

$$L^*(D) \text{ solves } \Omega_L = 0 \text{ and } D^*(L) \text{ solves } \Omega_D = 0.$$

The effect of an increase in funding uncertainty on a bank's equilibrium loans is therefore given by

$$\frac{dL^*}{d\sigma_M^2} = \frac{\partial L^*}{\partial \sigma_M^2} + \frac{\partial L^*}{\partial D}\frac{dD^*}{d\sigma_M^2}. \tag{14}$$

Funding uncertainty works via two channels: first, directly on the optimal choice of loans, and, second, indirectly via the impact on the optimal choice of deposits, which in turn feeds back to equilibrium loans (see Proposition 1). The impact on deposits can be written in the same way as $dD^*/d\sigma_M^2 = \partial D^*/\partial \sigma_M^2 + (\partial D^*/\partial L)\,(dL^*/d\sigma_M^2)$, and substituting this into the above gives

$$\frac{dL^*}{d\sigma_M^2} = \frac{\frac{\partial L^*}{\partial \sigma_M^2} + \frac{\partial L^*}{\partial D}\frac{\partial D^*}{\partial \sigma_M^2}}{\left(1 - \frac{\partial L^*}{\partial D}\frac{\partial D^*}{\partial L}\right)}. \tag{15}$$

The denominator of this expression is positive by the stability of equilibrium. Differentiating the first-order conditions yields the two partial effects

$$\frac{\partial D^*}{\partial \sigma_M^2} = \frac{\lambda M^*}{-\Pi_{DD} + \lambda \sigma_M^2} \text{ and } \frac{\partial L^*}{\partial \sigma_M^2} = \frac{-\lambda M^*}{-\Pi_{LL} + \lambda \sigma_M^2}, \tag{16}$$

for which the denominators are also positive by second-order conditions. From before, $\partial L^*/\partial D = \lambda\sigma_M^2/\left(-\Pi_{LL} + \lambda\sigma_M^2\right) > 0$. Putting these together and some

[18] Using a different approach, a similar observation that loan-deposit synergies may be especially pronounced during times of financial crisis has recently also been made by Gatev, Schuermann and Strahan (2009).

rearranging shows that

$$\frac{\partial L^*}{\partial \sigma_M^2} + \frac{\partial L^*}{\partial D}\frac{\partial D^*}{\partial \sigma_M^2} = \frac{-\lambda M^*}{-\Pi_{LL} + \lambda \sigma_M^2}\left(1 - \frac{\lambda \sigma_M^2}{-\Pi_{DD} + \lambda \sigma_M^2}\right). \tag{17}$$

This leads to the conclusion that

$$dL^*/d\sigma_M^2 \leq 0 \text{ if and only if } M^* \geq 0.$$

This condition can also usefully be expressed in terms of the bank's loan-to-deposit ratio. Letting $\ell \equiv L/D$ and the equity-to-deposit ratio $\kappa \equiv K/D$, the interbank market condition

$$M^* \geq 0 \text{ if and only if } \ell^* \geq 1 + \kappa^* \equiv \bar{\ell}.$$

In other words, a bank that is a net borrower in the interbank market, or, equivalently, has a loan-to-deposit ratio somewhat above 100%, responds to an increase in funding uncertainty by cutting back on its loan commitments (and thus also reducing the size of its balance sheet). The intuition is that a risk-averse bank gears its decisions to perform better in bad states of the world. With increased funding uncertainty, a wholesale market borrower becomes more concerned with outcomes where funding rates are high. So the bank optimally cuts back on loans to do relatively better in these states of the world.

The same method as above can also be used to show that equilibrium deposits increase with funding uncertainty, that is $dD^*/d\sigma_M^2 \geq 0$ if and only if $M^* \geq 0$ if and only if $\ell^* \geq \bar{\ell}$.

**Proposition 2** *An increase in funding uncertainty $\sigma_M^2$ induces a bank with a high (low) loan-to-deposit ratio $\ell^* \geq \bar{\ell}$ ($\ell^* < \bar{\ell}$) to:*
*(i) extend fewer (more) loans $L^*$ and take more (fewer) deposits $D^*$;*
*(ii) increase (decrease) interest rates on loans $r_L^*$ and deposits $r_D^*$.*

The 2007/9 financial crisis had the key characteristic that funding uncertainty in the interbank market increased sharply near its outset, and remained at unusually high levels for an extended period of time (see, e.g., Taylor and Williams, 2009). The result predicts that banks that have aggressively expanded their loan books, leading to high loan-to-deposit ratios, react to heightened funding uncertainty by essentially reversing their prior strategy: they now cut back loan commitments, while at the same time trying to attract a stronger deposit base with higher interest rates. Thus their money market exposures and loan-to-deposit ratios both fall.

Indeed, there is significant evidence that banks tried to reduce their exposure to the wholesale market from when the financial crisis began in the second half of

2007. The situation at the time was summarized by a bank manager at Alliance & Leicester: "Lenders are having to examine different funding routes. The increasing rates have no doubt been driven by the turmoil in the wholesale markets".[19] In the UK, for example, many banks have sought to replace short-term wholesale financing with more funds from retail customers by raising interest rates on existing deposit accounts and introducing various new savings products.

It is also plain that the recent financial crisis has led to banks cutting back on loans, thereby making it more difficult and costly for retail and corporate customers to borrow. For example, it was noted that "banks have cut overdraft facilities and unused credit lines, withdrawn from lending syndicates and abruptly called in loans. When they do lend, they are charging higher arrangement fees and interest at margins over their cost of funding that are considerably higher than they were" (*The Economist*, 24 January 2009). Although there are, of course, many reasons behind this (others to which I turn in the following sections), it is consistent with the result from Proposition 2 for highly leveraged banks.

It is well-known that the UK banking sector has become highly extended in recent years. For instance, the average loan-to-deposit ratio of three of the largest players, Barclays, Lloyds Banking Group and Royal Bank of Scotland, increased from around 100% in the early 2000s to 150% in 2008. More recently, however, several UK banks, including Royal Bank of Scotland, have "set themselves the aim of achieving a loan-to-deposit ratio of no more than 100% over the next five years" (*Financial Times*, 19 June 2009). Finally, Northern Rock, the UK bank that was rescued by the Bank of England near the beginning of the financial crisis in September 2007, also relied heavily on short-term funding from wholesale money markets (see, e.g., Shin, 2009).[20]

Conversely, the result predicts that banks with relatively low loan-to-deposit ratios—perhaps those that have had less aggressive credit strategies in the past—react to increased funding uncertainty by reducing their lending exposure in the wholesale market. One interpretation of this is that funding uncertainty causes liquidity in the interbank market to dry up: previous borrowers want to borrow less and lenders want to lend less than before. In other words, the demand for

[19] This quote is taken from the *Financial Times*, 1 December 2007. Alliance & Leicester is a medium-sized British bank (and former building society) that was subsequently taken over by Banco Santander of Spain (in October 2008).

[20] It is also interesting to note that some of the banks that have been hit hardest by the crisis internationally had unusually high loan-to-deposit ratios at its outset. Based on figures from 2007, Kaupthing and Landsbanki, two of the largest Icelandic banks, were reported to have loan-to-deposit ratios of 226% and 142% respectively, while Allied Irish and Bank of Ireland, two of the largest Irish banks, both had loan-to-deposit ratios of 158% (see *Financial Times*, 4 October 2008).

interbank funding and its supply by commercial banks decrease simultaneously. In some cases, central banks may consequently end up being the only remaining parties left to provide funds in these markets.

It is also worth stressing that *none* of these effects would apply in a model with risk-neutral banks, but they *all* appear even with an arbitrarily small degree of risk aversion. Note also that, with mean-variance utility, the result from Proposition 2 applies equally to an increase in risk aversion $\lambda$, holding the degree of funding uncertainty $\sigma_M^2$ fixed (or to combinations of the two).

# 5 Equity capital impacts

Funding uncertainty also opens up a key role for a risk-averse bank's equity capital. By contrast, with risk-neutral banks, changes in the amount of equity on the balance sheet have no impact on equilibrium loan and deposit choices, as these are separable in the bank's profit function $\Pi = (r_L - r)\, L + (r - r_D)\, D + rK$.

For a risk-averse bank, the impact of a change in equity capital can be worked out in a similar way to funding uncertainty in the previous section. Again recalling the two first-order conditions for loans and deposits that determine the overall equilibrium, it follows that

$$\frac{dL^*}{dK} = \frac{\partial L^*}{\partial K} + \frac{\partial L^*}{\partial D}\frac{dD^*}{dK}. \tag{18}$$

Equity capital also affects the optimal loan decision via two channels; the direct channel, and indirectly via the optimal choice of deposits, which feeds back to equilibrium loans. Since the impact on deposits is determined analogously, $dD^*/dK = \partial D^*/\partial K + (\partial D^*/\partial L)\,(dL^*/dK)$, this can be rewritten as

$$\frac{dL^*}{dK} = \frac{\frac{\partial L^*}{\partial K} + \frac{\partial L^*}{\partial D}\frac{\partial D^*}{\partial K}}{\left(1 - \frac{\partial L^*}{\partial D}\frac{\partial D^*}{\partial L}\right)}, \tag{19}$$

where the denominator is positive by stability. Differentiating the first-order conditions yields the two partial effects

$$\frac{\partial D^*}{\partial K} = \frac{-\lambda\sigma_M^2}{-\Pi_{DD} + \lambda\sigma_M^2} \text{ and } \frac{\partial L^*}{\partial K} = \frac{\lambda\sigma_M^2}{-\Pi_{LL} + \lambda\sigma_M^2}, \tag{20}$$

for which the denominators are also positive by second-order conditions. From before, $\partial L^*/\partial D = \lambda\sigma_M^2/\left(-\Pi_{LL} + \lambda\sigma_M^2\right) > 0$. Putting these together and some rearranging yields

$$\frac{\partial L^*}{\partial K} + \frac{\partial L^*}{\partial D}\frac{dD^*}{dK} = \frac{\lambda\sigma_M^2}{-\Pi_{LL} + \lambda\sigma_M^2}\left(1 - \frac{\lambda\sigma_M^2}{-\Pi_{DD} + \lambda\sigma_M^2}\right). \tag{21}$$

This shows that, in general, increases in equity capital lead to increases in equilibrium loans, $dL^*/dK > 0$.

The same arguments on the deposits side can be used to show that, by contrast, increases in equity capital lead to lower equilibrium deposits, so $dD^*/dK < 0$.

**Proposition 3** *In the presence of funding uncertainty $\sigma_M^2 > 0$, a decrease (increase) in equity capital $K$ induces a bank to:*
*(i) extend fewer (more) loans $L^*$ and take more (fewer) deposits $D^*$;*
*(ii) increase (decrease) interest rates on loans $r_L^*$ and deposits $r_D^*$.*

This result is somewhat stronger than the previous one in that it predicts that decreases in equity capital lead to contractions in loan-to-deposit ratios and increased interest rates on loans and deposits for all banks, and not just those banks that are net borrowers in the wholesale market.

Proposition 3 also speaks directly to the pattern of banks' attempts at "derisking" in the 2007/9 credit crunch. As the crisis unfolded in 2008, a large number of banks found themselves burning through their equity capital due to writedowns on risky loans and other securities, as well as trading losses (see, e.g., Brunnermeier, 2009). The result provides an explanation for why this makes banks cut back on loan commitments: all else equal, decreases in equity capital leave a bank more exposed to interbank market borrowing, which is risky in the presence of funding uncertainty. A risk-averse bank rationally responds by cutting back its loan-to-deposit ratio. Again, all else equal, this leads to the interest rates charged on loans to increase, and the rates paid to depositors to increase.

Taken together, the results from the model help explain the emerging base of stylized facts on bank lending in the financial crisis. For example, using data on syndicated loans, Ivashina and Scharfstein (2009) document that US banks sharply decreased lending, especially around the height of the crisis in the 4th quarter of 2008. Importantly, they also find that banks that had higher better access to deposit finance (with higher deposit-to-asset ratios and thus less reliance on short-term debt) cut their lending by less than other banks. This seems consistent with Propositions 2 and 3 taken together: losses in equity capital cause all banks to contract lending, but in an environment with heightened funding uncertainty banks with a strong deposit base cut by relatively less.[21]

[21] Of course, as Ivashina and Scharfstein (2009) also note, there are competing explanations for

Conversely, if a bank builds up its equity capital, then this enables it to extend more loans, while relying less on its deposit base. This reverse conclusion also has a number of interesting implications. First, in the context of financial crises, it provides a reason why bank recapitalizations (by shareholders or governments) can be useful in counteracting the upward pressure on interest rates on loans due to increases in funding uncertainty (Proposition 2) or prior equity losses. Second, taking a time-series perspective, it may also help explain how an extended period of strong bank profitability and equity accumulation (as in the mid-2000s, for example) can make it rational for banks to increase their loan-to-deposit ratios whilst relying more heavily on the wholesale market for funding. Third, taking a cross-sectional perspective, the result is also consistent with evidence from Hubbard, Kuttner and Palia (2002) that low-capital banks tend to charge higher interest rates on loans to their borrowers (especially when these are small firms) than well-capitalized banks.

More generally, the interesting thing about Proposition 3 is that a bank's balance sheet constraint leads to something akin to a "wealth effect" associated with equity capital—even in a model effectively set in a mean-variance framework.

# 6 Bank profitability and consumer welfare

I have so far focused on the impact of funding uncertainty on prices and quantities, namely equilibrium interest rates and a bank's balance sheet. Based on this analysis, I now draw out the implications for two key measures of surplus: bank profits and consumer welfare.

□ **Bank profitability.** The effect of a change in funding uncertainty on a risk-averse bank's equilibrium expected profits can be written as

$$\frac{dE\left[\Pi^*\right]}{d\sigma_M^2} = E[\Pi_L]\frac{dL^*}{d\sigma_M^2} + E[\Pi_D]\frac{dD^*}{d\sigma_M^2}. \tag{22}$$

Suppose first that the bank is a net borrower in the wholesale market, so $M \geq 0$. Then the first-order conditions (from (6) and (7) and the following discussion) imply that $E\left[\Pi_L\right] \geq 0$ and $E\left[\Pi_D\right] \leq 0$. By Proposition 2, an increase in funding uncertainty then leads to a decrease in loans and an increase in deposits, so $dL^*/d\sigma_M^2 \leq 0$ and $dD^*/d\sigma_M^2 \geq 0$. It follows that equilibrium expected profits must decrease, $dE\left[\Pi^*\right]/d\sigma_M^2 \leq 0$. These arguments work in the reverse way for the case when $M \leq 0$, also leading to opposite signs and hence $dE\left[\Pi^*\right]/d\sigma_M^2 \leq 0$.

an observed reduction in bank lending, notably a decrease in the demand for loans. (See also note 7 above.)

**Proposition 4** *An increase in funding uncertainty $\sigma_M^2$ decreases a bank's equilibrium expected profit $E[\Pi^*]$.*

The basic intuition for the result is that higher funding uncertainty tightens the "utility constraint" on the bank's expected profits, thus distorting its optimal loan and deposit choices further away from the (profit-maximizing) risk-neutral case. This in turn reduces the bank's overall expected profits. Proposition 4 thus suggests that increased uncertainty about funding conditions *per se* leads to a reduction in bank profitability. This is consistent with evidence for a sharp drop in banks' returns on equity in the second half of 2007 when funding uncertainty initially increased (Bank of England *Financial Stability Report*, April 2008, p. 38). It is also consistent, all else equal, with decreases in banks' stock prices and market capitalizations.

□ **Consumer welfare.** In the benchmark model, a bank is effectively a monopolist in the market for loans and a monopsonist in that for deposits. In the absence of funding uncertainty (or with risk-neutrality), therefore, equilibrium features too few loans (for which the bank's customers pay too much interest) and too few deposits (on which depositors receive too little interest) and monopoly profits for the bank in both markets (where $r_L^* > \bar{r} > r_D^*$).

Recall from Proposition 2 that a risk-averse bank reacts asymmetrically to an increase in funding uncertainty—it either decreases loans and increases deposits or vice versa. This has important implications for the *relative* levels of bank profits and consumer welfare between these two markets. The idea is straightforward: suppose that the market for loans is very attractive (for example, because borrowers have a high willingness-to-pay) relative to the market for deposits. If funding uncertainty is low, the bank will wish to have a high loan-to-deposit ratio and to borrow heavily in the interbank market. As funding uncertainty increases, the bank reduces its loan-to-deposit ratio, with zero interbank exposure $L^* = D^* + K$ in the limit as $\sigma_M^2 \to \infty$. The point is that the level of deposits that satisfies this zero-exposure constraint may well be *much* higher than that associated with low levels of funding uncertainty—and may even exceed that of a competitive market.

This possibility is most easily illustrated with a linear loan demand function $f_L(L) = \alpha_L - \beta_L L$, and a linear deposit supply function $f_D(D) = \alpha_D + \beta_D D$. Letting $\psi_L \equiv (\alpha_L - \bar{r})$ and $\psi_D \equiv (\bar{r} - \alpha_D)$, where $\alpha_L > \bar{r} > \alpha_D$, note that the "first-best", competitive outcome in which both loans and deposits are priced at the bank's expected marginal cost of funding, involves $L^{FB} = \psi_L/\beta_L$ (for which $r_L = \bar{r}$) and $D^{FB} = \psi_D/\beta_D$ (for which $r_D = \bar{r}$). By contrast, the two first-order conditions for a risk-averse bank can be written as $\Omega_L \equiv (\psi_L - 2\beta_L L) - \lambda\sigma_M^2 (L - D - K) = 0$ and $\Omega_D \equiv (\psi_D - 2\beta_D D) + \lambda\sigma_M^2 (L - D - K) = 0$. In the limit as $\sigma_M^2 \to \infty$, these can be solved for

$$L^* = \frac{(\psi_L + \psi_D) + 2\beta_D K}{2(\beta_L + \beta_D)} \text{ and } D^* = \frac{(\psi_L + \psi_D) - 2\beta_L K}{2(\beta_L + \beta_D)}. \tag{23}$$

If the market for loans is very attractive in that $\psi_L$ is high, then this increases equilibrium loans, but also increases equilibrium *deposits* (recalling the loan-deposit synergies result from Proposition 1).[22] For sufficiently large $\psi_L$, it is therefore possible that $r_D^* > \bar{r}$ (if and only if $D^* > D^{FB}$), so deposits become a "loss leader" for the bank in that the deposit rate exceeds it own wholesale funding cost. Conversely, equilibrium depositor welfare exceeds that of a competitive market. Of course, the bank's loan business is highly profitable under these conditions, and the bank also expects to make positive profits overall.[23]

Similar arguments can also be applied to show that loans may become a loss leader for the bank (with positive profits from the deposits business), so $r_L^* < \bar{r}$, in which case borrower welfare exceeds that of a competitive market. But since the impact of funding uncertainty is asymmetric (Proposition 2), it is, of course, not possible for both sides of the bank to be loss-making at the same time.[24]

**Proposition 5** *In the presence of funding uncertainty $\sigma_M^2 > 0$, it is possible for either a bank's loan or deposit business to be loss-making (in expectation), that is $r_L^* < \bar{r}$ or $r_D^* > \bar{r}$.*

This result shows that risk-based synergies between the two sides of a bank's balance sheet (Proposition 1) can lead to cross-subsidization even where a bank's loan and deposit businesses are entirely independent in terms of demand and supply conditions as well as operating costs.[25]

While it is clear that competition for bank deposits has intensified since the beginning of the financial crisis, it can be difficult to tell in practice at what point

[22] The condition for equilibrium deposits to be non-negative is $K \leq (\psi_L + \psi_D)/2\beta_L$. (See also note 12 above.)

[23] It easy to check that the bank's expected profits (from both loans and deposits) are positive even with zero capital $E[\Pi^*]_{K=0} = \frac{1}{4}(\alpha_L - \alpha_D)^2/(\beta_L + \beta_D)$, and that profits are higher with more equity capital.

[24] Put differently, either $r_L^* > r_D^* > \bar{r}$ (so deposits are loss-making, but loans are highly profitable) or $\bar{r} > r_L^* > r_D^*$ (so loans are loss-making, but deposit funds are very cheap), while there is always a positive intermediation margin, $(r_L^* - r_D^*) > 0$, in equilibrium. (See also note 16 above.)

[25] Note also that the bank would not wish to shut down or sell its loss-making business since this would expose it to infinite funding uncertainty from a stand-alone operation based only on the other business.

deposits actually turn into a loss leader. Nonetheless, some recent developments in the UK are striking: "Banks are seeking to attract retail inflows by increasing deposit rates: retail bonds now pay around 200 basis points above the risk-free rate, compared to a sub-zero spread in 2005." (Bank of England *Financial Stability Report*, December 2009, p. 38).

The broader point here is that heightened funding uncertainty and loan-deposit synergies can have surprisingly strong implications for consumer welfare.

# 7 Interest rate pass-through

Central banks around the world responded to the recent turmoil in financial markets by aggressively cutting interest rates (mainly throughout the course of 2008), in order to encourage bank lending and stimulate demand more generally. However, many policymakers and commentators expressed surprise at the apparently small impact that this loosening of monetary policy had on interest rates, especially across credit markets. For example, the minutes of the Federal Open Markets Committee (FOMC) noted that "some members were concerned that the effectiveness of cuts in the target federal funds rate may have been diminished by the financial dislocations, suggesting that further policy action might have limited efficacy in promoting a recovery in economic growth" (FOMC Minutes of the Meeting of 28-29 October 2008). I now argue that heightened uncertainty about banks' funding conditions in money markets provides an explanation for this apparent reduction in monetary policy effectiveness.

Within the context of the model, a central bank's control of the short-term interest rate can be thought of as affecting the expected money market rate $\bar{r}$. The impact of a change in the interbank rate induced by a monetary policy adjustment is then captured by the rates of interest pass-through on loans and deposits,

$$\rho_L \equiv dr_L^*/d\bar{r} \text{ and } \rho_D \equiv dr_D^*/d\bar{r}.$$

So if the expected interest rate in money markets decreases by 100 basis points, then equilibrium loan and deposit rates decrease (approximately) by $100\rho_L$ and $100\rho_D$ basis points respectively.

Interest rate pass-through on loans can also be written as

$$\rho_L = f_L'(L^*)\frac{dL^*}{d\bar{r}}, \tag{24}$$

where, using the same method as in previous sections, there is a direct and an indirect effect as follows:

$$\frac{dL^*}{d\bar{r}} = \frac{\frac{\partial L^*}{\partial \bar{r}} + \frac{\partial L^*}{\partial D}\frac{\partial D^*}{\partial \bar{r}}}{\left(1 - \frac{\partial L^*}{\partial D}\frac{\partial D^*}{\partial L}\right)}. \tag{25}$$

Now, using the expressions for $\partial L^*/\partial D$ and $\partial D^*/\partial L$ from (11) and (12), noting that $\partial L^*/\partial \bar{r} = -1/(-\Pi_{LL} + \lambda\sigma_M^2)$ and $\partial D^*/\partial \bar{r} = 1/(-\Pi_{DD} + \lambda\sigma_M^2)$, and some further rearranging yields

$$\rho_L = \frac{-f_L'(L^*)}{-\Pi_{LL} + \lambda\sigma_M^2\left(1 + \frac{-\Pi_{LL}}{-\Pi_{DD}}\right)}. \tag{26}$$

The same approach on the deposits side gives

$$\rho_D = \frac{f_D'(D^*)}{-\Pi_{DD} + \lambda\sigma_M^2\left(1 + \frac{-\Pi_{DD}}{-\Pi_{LL}}\right)}. \tag{27}$$

The rates of interest pass-through are both positive, so a bank optimally increases interest rates on both loans and deposits in response to a higher expected money market rate (and vice versa). However, by inspection of (26) and (27), it is also clear that funding uncertainty (that is, higher $\sigma_M^2$) exerts a strong downward pressure on pass-through in both markets.

Characterizing the necessary condition for interest rate pass-through to be lower with funding uncertainty turns out be messy since, in general, changes in $\Pi_{LL}$ and $\Pi_{DD}$ need to be taken into account (thus involving third-order effects). Given that these are hard to interpret, I instead present a set of simple sufficient conditions for pass-through to be dampened by uncertainty in the money markets. Let $\gamma_L \equiv -Lf_L''(L)/f_L'(L)$ and $\gamma_D \equiv Df_D''(D)/f_D'(D)$ denote measures of curvature of loan demand and deposit supply respectively. Noting that $-\Pi_{LL} = -f_L'(L^*)\left[2 - \gamma_L(L^*)\right]$ and $-\Pi_{DD} = f_D'(D^*)\left[2 - \gamma_D(D^*)\right]$ yields the following result.

**Proposition 6** *(i) If loan demand curvature $\gamma_L$ and deposit supply curvature $\gamma_D$ are both constant, then interest rate pass-through on loans $\rho_L$ and deposits $\rho_D$ is lower in the presence of funding uncertainty $\sigma_M^2 > 0$ than when $\sigma_M^2 = 0$;*
*(ii) If loan demand and deposit supply are both linear (so $\gamma_L = 0$ and $\gamma_D = 0$), then interest rate pass-through on loans $\rho_L$ and deposits $\rho_D$ is decreasing in funding uncertainty $\sigma_M^2$;*
*(iii) interest rate pass-through on loans and deposits is zero (so $\rho_L = \rho_D = 0$) in the limit as funding uncertainty $\sigma_M^2 \to \infty$.*

Part (i) of the result covers a fairly wide range of well-known demand and supply specifications. For example, loan demands that are quadratic ($\gamma_L = -1$), linear ($\gamma_L = 0$), exponential ($\gamma_L \to 1$) or have constant elasticity ($\gamma_L = 1 + 1/\eta_L$, where

$\eta_L > 0$ is the price elasticity of demand for loans) all satisfy the constant-curvature property. Part (ii) is easily verified by inspection of (26) and (27) since $-\Pi_{LL}$ and $-\Pi_{DD}$ are both constants with linear demand and supply. Finally, to understand part (iii) of the result, recall that in the limit as $\sigma_M^2 \to \infty$, the balance sheet constraint becomes $L^* = D^* + K$. In response to higher funding costs, a bank would want to increase interest rates on both loans and deposits, but this would mean fewer loans and more deposits—thus violating the balance sheet constraint. Hence, the rate of interest pass-through is zero.[26]

Although not completely general, Proposition 6 suggests that interest rate pass-through will typically be dampened when uncertainty on banks funding conditions is high.[27] Put differently, banks' pricing of loans and deposits becomes more rigid and less responsive to "shocks." In this sense, monetary policy becomes less effective at influencing a bank's decision-making process—with market interest rates on loans and deposits completely frozen in the limiting case. This may help provide an explanation for the reduced impact that interest rate cuts by central banks in the 2007/9 financial crisis are commonly said to have had.[28]

# 8 Extensions

The benchmark model offers a stylized way to capture the impact of funding uncertainty on a bank's balance sheet, equilibrium interest rates on loans and deposits, as well as for the effectiveness of monetary policy via interest rate pass-through. I show in this section that the key insights obtained from the preceding analysis are considerably more general.

□ **Exposure to multiple risks**. To focus sharply on the impact of funding uncertainty, the benchmark model makes the simplifying assumption that the bank faces a single risk. In practice, of course, a bank faces additional risks such as credit risks in its loan portfolio or uncertainty on the deposits side. Modeling these can make the analysis much more complicated. For example, if the additional risks on loans

[26] See also the example with linear demand and supply from Section 6, noting that $L^*$ and $D^*$ in (23) are both independent of the interbank rate $\bar{r}$ (since $\psi_L + \psi_D = \alpha_L - \alpha_D$).

[27] In the risk-neutral case, both pass-through rates are independent of funding uncertainty (and also independent of one another). Note also that, in general, the *level* of interest rate pass-through is itself quite sensitive to the value of curvature parameter. For example, with risk-neutrality, pass-though on loans $\rho_L = 1/[2 - \gamma_L(L^*)]$ is less than 50% if demand is linear or concave, but exceeds 100% with constant-elasticity demand. Finally, notice that interest pass-through in the risk-neutral case is constant only if the curvature parameter is constant, $\gamma_L(L) = \gamma_L$.

[28] It also suggests that any empirical evidence for banks adjusting interest rates by less than otherwise would have may in fact reflect a rational response to heightened funding uncertainty rather than being indicative of collusive behaviour, for example.

and deposits are correlated, a bank's decisions may become interdependent even in the absence of funding uncertainty—thus skewing the theoretical benchmark that implicitly underlies Proposition 1 especially.[29] Nonetheless, under fairly mild conditions, the key insights from the benchmark model are preserved in settings with multiple risks.

Using the same arguments as in Section 3, the first-order conditions for the bank can be written as

$$\Omega_L \equiv E[\Pi_L] - \lambda \cdot cov(\Pi, \Pi_L) = 0 \text{ and } \Omega_D \equiv E[\Pi_D] - \lambda \cdot cov(\Pi, \Pi_D) = 0. \quad (28)$$

Suppose now that the marginal risks on loans and deposits are given by

$$cov(\Pi, \Pi_L) = \sigma_M^2 M + \upsilon_L(L, D) \text{ and } cov(\Pi, \Pi_D) = -\sigma_M^2 M + \upsilon_D(L, D) \quad (29)$$

where $\upsilon_L(L, D)$ reflects the marginal risk on loans due to other risk factors, and, similarly, $\upsilon_D(L, D)$ on the deposits side. I allow both of these marginal risks to depend arbitrarily on loans and deposits, while continuing to assume that the second-order conditions as well as stability conditions are satisfied.[30]

As in the benchmark model, loan-deposit synergies (Proposition 1), $\partial L^*/\partial D > 0$ and $\partial D^*/\partial L > 0$, exist if and only if marginal profits are negatively correlated, $cov(\Pi_L, \Pi_D) < 0$, which in turn is equivalent to $\sigma_M^2 > \upsilon_{LD}(\cdot)$. Unsurprisingly, a sufficient (and, in a sense, necessary) condition for loan-deposit synergies is that such complementarities also exist amongst the other risk factors, that is $\upsilon_{LD}(\cdot) \leq 0$. In general, however, loan-deposit synergies always obtain for large enough funding uncertainty $\sigma_M^2$.

It is also easy to check, using the same techniques as in the benchmark analysis, that Proposition 2 and 3 continue to hold with multiple risks. In particular, increased funding uncertainty induces a bank with a high loan-to-deposit ratio to increase interest rates on loans and deposits, while the same conclusion also goes through, in general, in response to reductions in equity capital.

For Proposition 4, recall that expected profits change with funding uncertainty according to $dE[\Pi^*]/d\sigma_M^2 = E[\Pi_L](dL^*/d\sigma_M^2) + E[\Pi_D](dD^*/d\sigma_M^2)$. Consider the case where the bank is a net borrower in the money market, $M^* \geq 0$. By Proposition 2, $dL^*/d\sigma_M^2 \leq 0$ and $dD^*/d\sigma_M^2 \geq 0$. Now observe, from the first-order conditions,

[29] Note also that with multiple risks, increases in funding uncertainty need no longer be equivalent to increases in risk aversion (as they are in the benchmark model).

[30] A natural example that is a special case of this formulation has the bank's profit function $\Pi = (1-\theta)r_L L - r_D D - rM$, where $\theta \in [0, 1]$ captures the uncertain proportion of loans that turn out to be non-performing (which is taken to be independent of funding uncertainty).

that $E[\Pi_L] = cov(\Pi, \Pi_L)$ and $E[\Pi_D] = cov(\Pi, \Pi_D)$. Therefore, sufficient conditions for expected profits to decrease $dE[\Pi^*]/d\sigma_M^2 \leq 0$ are that $cov(\Pi, \Pi_L) \geq 0$ and $cov(\Pi, \Pi_D) \leq 0$, which again always obtain for large enough funding uncertainty $\sigma_M^2$. Note also that these conditions are equivalent to $dL^*/d\lambda \leq 0$ and $dD^*/d\lambda \geq 0$; in other words, an increase in risk aversion induces a highly extended bank to cut back its loan commitments and increase its deposit base.

Examples for loss-leading behaviour on the loan or deposit sides (Proposition 5) can also be constructed under multiple risks, even though there often is a tendency for such additional risks to reduce both a bank's optimal deposit and loan volumes, thus making loss leaders less likely. Finally, the analysis of interest rate pass-through (Proposition 6) unfortunately becomes much more complicated with multiple risks, although I expect that heightened funding uncertainty still dampens pass-through in a similar sense to the benchmark model.

□ **Competition between banks**. The setup underlying the benchmark model can also easily be extended to competition between $N \geq 2$ risk-averse banks.

Suppose that the inverse demand curve for loans from bank $j$ is given by $r_L^j = f_L\left(L^j + \delta_L \sum_{k \neq j} L^k\right)$, where $f_L'(\cdot) < 0$ similar to above, and $\delta_L \in [0, 1]$ is a measure of (symmetric) product differentiation between the loans associated with different banks. Similarly, deposit supply for bank $j$ is given by $r_D^j = f_D\left(D^j + \delta_D \sum_{k \neq j} D^k\right)$, where $f_D'(\cdot) > 0$ and $\delta_D \in [0, 1]$. This setup now effectively nests all market structures ranging from perfect competition (with $\delta_L = \delta_D = 1$ and $N \to \infty$) to monopoly (with $\delta_L \to 0$ and $\delta_D \to 0$ or $N = 1$). The bank's profits are $\Pi^j = r_L^j L^j - r_D^j D^j - r^j M^j$, where $r^j$ is the uncertain funding rate (possibly bank-specific) on its money market exposure $M^j$.

As above, bank $j$ maximizes expected utility subject to its balance sheet constraint:

$$\max_{L^j, D^j} E\left[U\left(\Pi^j\right)\right] \text{ subject to } M^j = L^j - D^j - K^j. \tag{30}$$

Again, using Taylor expansions (or Stein's lemma) as in the benchmark model, the first-order conditions can be written as

$$\Omega_L^j \equiv E\left[\Pi_L^j\right] - \lambda \cdot cov\left(\Pi^j, \Pi_L^j\right) = 0 \tag{31}$$

and

$$\Omega_D^j \equiv E\left[\Pi_D^j\right] - \lambda \cdot cov\left(\Pi^j, \Pi_D^j\right) = 0, \tag{32}$$

where, with a slight abuse of notation, $\Pi_L^j \equiv \partial \Pi^j / \partial L^j$ and $\Pi_D^j \equiv \partial \Pi^j / \partial D^j$. Moreover, it is easy to check that $cov\left(\Pi^j, \Pi_L^j\right) = \sigma_M^2 M^j$, $cov\left(\Pi^j, \Pi_D^j\right) = -\sigma_M^2 M^j$ and

$cov\left(\Pi_L^j, \Pi_D^j\right) = -\sigma_M^2$, all exactly analogous to the single-bank setting. Although a bank's profits component, of course, varies with different forms of competition, the funding uncertainty component of the problem is essentially unchanged—leading to loan-deposit synergies as in Proposition 1.

In the symmetric Nash equilibrium, in which each bank has the same amount of equity capital $K^j = K/N$ and letting $M^j = M^*/N$, the first-order conditions become

$$\Omega_L^* \equiv E\left[\Pi_L^*\right] - \lambda\sigma_M^2 M^*/N = 0 \text{ and } \Omega_D^* \equiv E\left[\Pi_D^*\right] + \lambda\sigma_M^2 M^*/N = 0 \qquad (33)$$

for loans and deposits respectively. From this, it is clear that the main insights from the benchmark model carry over to this richer setting with competition between banks and differentiated products. The reason is that Propositions 2 to 5 do not rely on the details of the profit function, but rather only (in some cases) on whether a bank is a net lender or borrower in the interbank market.[31]

Finally, although the degree of interest rate pass-through is, of course, affected by market structure, the general tendency for funding uncertainty to dampen pass-through is preserved in that Proposition 6 also applies, in exactly the same way, to this setting.

# 9 Conclusion

Uncertainty over funding conditions in the money market makes a fundamental difference to an otherwise standard model of banking due to the risk-based synergies between loans and deposits that it creates. In banking systems with high loan-to-deposit ratios such as the UK, increased funding uncertainty tends to make the banks themselves, their shareholders and borrowers worse off, while depositors may end up benefitting substantially. Moreover, banks rationally pass on to borrowers and depositors a smaller proportion of changes in the central bank's policy rate than in a world without funding uncertainty.

In broad terms, these results resemble the emerging base of stylized facts on bank behaviour in the recent financial crisis, notably on reduced bank lending, increased competition for retail deposits, and reduced monetary policy effectiveness. Thereby, it is consistent with a view that the turmoil in money markets that began in the

[31] Note, however, that the impact of funding uncertainty becomes negligible under perfect competition between banks in the limit as $N \to \infty$. Additional strategic effects may also emerge if there is significant heterogeneity between banks, for instance, in form of differences in cost efficiency across institutions. Broadly speaking, the impact of these will depend on the precise sources of asymmetry and on how competition is best modelled.

summer of 2007 played an important role in causing and prolonging the crisis. It also may help explain why banks with a strong deposit base appear to have done better throughout these events, and why other banks are now aiming to reduce their loan-to-deposit ratios back towards 100%.

An advantage of the model presented here is that it delivers a rich set of implications using a simple framework driven solely by uncertainty over banks' funding conditions. However, thinking about bank behaviour and its implications for the economy is a complex task and the model abstracts from many important issues. In particular, future work might fruitfully try to integrate elements of asymmetric information between banks into the modelling approach presented here, and more research into why funding conditions became so volatile in the first place is clearly also still needed.

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