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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 that increased funding uncertainty: (i) creates risk-based loan-deposit synergies, (ii) often causes banks' lending volumes and their profitability to decline, (iii) can explain more intense competition for retail deposits (including deposits turning into a "loss leader"), and (iv) typically dampens the rate of pass-through from changes in the central bank's policy rate to market interest rates. These results can explain some elements of commercial banks' behaviour and the reduced effectiveness of monetary policy during the 2007/9 financial crisis.

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

JEL classifications: D40 (market structure and pricing), E43 (interest rates), 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 unsecured (i.e., uncollateralized) term loans between banks (measured, for example, by three-month LIBOR), diverged substantially from the central bank's policy rate—and remained unusually volatile for an extended period of time. Moreover, such 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, partial-equilibrium model to show how such heightened uncertainty over funding conditions in the money markets can help explain several diverse aspects of commercial banks' behaviour as 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 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. The bank has a degree of market power in loan and deposit markets, while it acts as a price-taker in the money market. 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 interbank markets, but, more generally, could also represent uncertainty over possible actions by the central bank that affect a bank's funding conditions.[1]

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

[1] I do not attempt to explain what causes such uncertainty over funding conditions, but rather 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. Note especially that such unsecured borrowing is not backed with collateral requirements (in contrast, say, to repurchase agreements ("repos") between banks).

with asset-liability management. This result contributes to an emerging literature on loan-deposit synergies (see, e.g., Kashyap, Rajan and Stein, 2002, and Gatev, Schuermann and Strahan, 2009) that focuses on interactions between the two sides of a bank's 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 commercial banks throughout the course of 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).[2] 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, 2010).

Funding uncertainty also has surprisingly strong implications for bank profitability and consumer welfare in loan and deposit markets. In particular, increased uncertainty over funding conditions *per se* 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 its deposits business 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.[3]

[2] 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).

[3] These generally rely on product complementarities (e.g., razor and razor blades) or on particular features of the strategic interaction between firms (e.g., related to entry deterrence). 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).

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 (Proposition 6). This provides an explanation for why monetary policy may have been less effective at influencing bank behaviour, and why the common 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. 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.

The fact that heightened funding uncertainty can account for such diverse aspects of observed bank behaviour distinguishes this mechanism from others. For example, in a standard model, a decrease in the demand for loans will typically also lead 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 yet striking mechanism that connects all these elements of bank behaviour.

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 presents several natural extensions to the benchmark model; these show that the key insights are robust to a variety of changes in model specification, notably to the presence of multiple risks (such as credit risks in a bank's loan portfolio) and to different forms of competition between banks. Section 9 offers concluding comments.

2 A simple model

I begin by considering a simple, partial-equilibrium model of a 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.

The bank has a degree of market power in 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.[4] 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 $f_D'(\cdot) > 0$.[5]

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; let τ denote the (per-unit) cost of capital. 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,[6] but does not precisely know the funding rate r when it makes decisions on its loans and deposits. It is useful to think of a bank's funding rate as the central bank's policy rate plus a bank-specific spread. Taylor and Williams (2009) document how interest rates on unsecured (i.e., uncollateralized) term loans between banks diverged substantially from the central bank's policy rate—and remained unusually volatile for an extended period of time during the recent crisis. This uncertainty over funding conditions is most naturally associated with variability in the spread (although there might also be some uncertainty over possible actions by the central bank). For the following analysis, let $\bar{r}$ denote the expected funding

[4] 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.

[5] Following Allen and Gale (2000, Chapter 8) and Boyd and de Nicoló (2005), I here assume implicitly that deposits are fully insured, so the supply of funds does not depend on risk. The model could easily be extended to incorporate a flat-rate insurance premium per unit of deposits without affecting any of the results presented.

[6] 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).

rate and let σ_M^2 denote the (overall) degree of funding uncertainty, measured by 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.

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

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

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

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 Hughes and Mester (1998), Nishiyama (2007) and Ratti (1980) find evidence for different degrees of risk-averse behaviour by US commercial banks (or their managers).

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.[7]

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

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

To simplify notation, let $\Pi_L \equiv \partial\Pi/\partial L$ and $\Pi_D \equiv \partial\Pi/\partial D$, as well as $\Pi_{LL} \equiv \partial\Pi_L/\partial L$ and $\Pi_{DD} \equiv \partial\Pi_D/\partial D$. The bank's problem turns out to be well-behaved

[7] 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.

whenever the two second-order conditions for the underlying risk-neutral benchmark (where $\lambda = 0$) are satisfied. These 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.

Interior solutions for loans and deposits are guaranteed by $f_L(0) > \bar{r} > f_D(0)$ and $K \leq L$.[8] Note that $\Pi_{LD} \equiv \partial \Pi_L / \partial D = 0$ since there are no operating synergies between the loan and deposit sides of the bank (so also $\Pi_{DL} = 0$). In what follows, I focus on the interesting case where the bank's cost of capital τ is sufficiently low for it to be an active participant in loan and deposit markets. (I discuss the possibility of the bank making losses and shutting down in Section 6.)

The model is perhaps best thought of as capturing the behaviour of a small or medium-sized bank with a regional franchise that has some local market power, but which takes the price of non-deposit sources of funds as given (perhaps because this is determined at a national or international level). Interbank borrowing involves unsecured term loans with durations of three months or similar (rather than, say, collateralized overnight lending). Recent contributions by Allen and Gale (2000, Chapter 8), Boyd and de Nicoló (2005), Hannan and Berger (1991), Neumark and Sharpe (1992), Neven and Röller (1999), Stein (1998), and Wong (1997) analyze related models of loan and/or deposit markets, although none of these consider the impact of funding uncertainty in the money market.[9]

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

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

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

[8] The condition $K \leq L$ is sufficient to ensure that equilibrium deposits are non-negative. It is very 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.)

[9] Santomero (1984) provides a survey of the earlier literature that followed Klein (1971).

volume of its deposit base D, reflecting deposit rates below its own funding costs. Third, it makes a spread of $(r-\tau)$, which may be negative, on its equity capital K, reflecting its cost of capital together with the fact that equity implicitly relieves it from borrowing a corresponding amount in the wholesale market.[10]

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, 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.[11]

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.[12]

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

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

and

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

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

[10] It is probably most natural that the required return on equity capital exceeds the wholesale funding rate ($\tau>r$), but I do not require any assumptions on whether the spread $(r-\tau)$ is positive or negative in the subsequent analysis. (As noted above, I maintain the assumption that τ is sufficiently low for the bank to be an active participant in loan and deposits markets.)

[11] By definition, the risk premium μ 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.

[12] Stein's lemma states that if two random variables X and Y are bivariate normally distributed and $\varphi'(Y)<\infty$, then $cov(X,\varphi(Y))=E[\varphi'(Y)]\cdot cov(X,Y)$. See, e.g., Huang and Litzenberger (1988). To apply this result, note that if the funding rate r is normally distributed, then the bank's profits Π and marginal profits on loans Π_L and deposits Π_D are also all normally distributed.

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 $\Pi = r_L L - r_D D - rM - \tau K$, 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 $\Pi_{DD} < 0$).[13] 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 Π remains unaffected by funding uncertainty—although decisions on loans and deposits remain interdependent at the margin.

To see this interdependence more formally, let $L^*(D)$ solve the first-order condition for loans $\Omega_L = 0$, and differentiate to obtain that

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

where $\Omega_{LL} \equiv \partial \Omega_L / \partial L$ and $\Omega_{LD} \equiv \partial \Omega_L / \partial D$. The second-order condition for loans

$$\Omega_{LL} = \Pi_{LL} - \lambda \cdot var(\Pi_L) < 0, \tag{9}$$

since $E[\Pi_{LL}] = \Pi_{LL} < 0$ and $var(\Pi_L) = \sigma_M^2$. Since there are no operational synergies $\Pi_{LD} = \Pi_{DL} = 0$ (by assumption),

$$\Omega_{LD} = -\lambda \cdot cov(\Pi_D, \Pi_L). \tag{10}$$

These arguments show that loan-deposit synergies exist whenever an increase in deposits decreases the marginal risk that the bank faces on its *loans* (and vice versa), that is

$$\partial L^* / \partial D \geq 0 \text{ if and only if } cov(\Pi_D, \Pi_L) \leq 0.$$

It is easy to check that indeed $cov(\Pi_D, \Pi_L) = -\sigma_M^2 < 0$, and putting these results 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

[13] 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.

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. Note that this logic applies regardless of whether the bank is a borrower or a lender in the money market overall.

Proposition 1 thus 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).[14]

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. The proportion of a small increase in a bank's loan commitments that is funded by way of increased money market exposure is determined 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 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.[15]

[14] 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.

[15] Using a different approach, a similar observation that loan-deposit synergies are especially

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 regarding its impact on banks' interbank market exposure.

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

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

Let the associated interest rates on loans $r_L^* = f_L(L^*)$ and deposits $r_D^* = f_D(D^*)$.

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

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

The denominator of this expression is positive by the stability of equilibrium (that is, $0 < \partial L^*/\partial D < 1$ and $0 < \partial D^*/\partial L < 1$). Differentiating the first-order conditions yields the two partial effects

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

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

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

pronounced during times of financial crisis has recently also been made by Gatev, Schuermann and Strahan (2009).

This leads to the conclusion that

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

So, by the stability of equilibrium, the sign of $dL^*/d\sigma_M^2$ is thus determined by the direct effect $\partial L^*/\partial\sigma_M^2$ rather than by the indirect effect via deposits (which takes the opposite sign).

The last 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 $\ell^* \geq \bar{\ell}$. Since the change in a bank's money market position $dM^*/d\sigma_M^2 = (dL^*/d\sigma_M^2 - dD^*/d\sigma_M^2)$, it also follows that $dM^*/d\sigma_M^2 \leq 0$ if and only if $M^* \geq 0$ if and only if $\ell^* \geq \bar{\ell}$.

Proposition 2 *In equilibrium, an increase in funding uncertainty σ_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^*;
(iii) reduce the size of its interbank market position $|M^*|$.

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".[16] 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).[17]

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: Existing borrowers want to borrow less and lenders want to lend less than before. In other words, the demand for

[16] 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).

[17] 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 worth stressing that none of these effects would apply in a model with banks that are *always* risk-neutral, but they all appear even with an arbitrarily small (but positive) degree of risk aversion.

Furthermore, with mean-variance utility, the result from Proposition 2 applies equally to an increase in risk aversion λ, holding the degree of funding uncertainty σ_M^2 fixed—or to any combination of increases in these two parameters. So an interbank market borrower (with $M^* > 0$) responds to an increase in risk aversion (higher λ) by reducing loan commitments, attracting more deposits, and cutting money market borrowing ($dL^*/d\lambda < 0$, $dD^*/d\lambda > 0$, $dM^*/d\lambda < 0$). Note especially that this last conclusion also holds if the bank initially was risk-neutral (with $\lambda = 0$), and then *becomes* risk-averse—for example, in the context of a financial crisis.

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 $\Pi = (r_L - r)\, L + (r - r_D)\, D + (r - \tau)K$.

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.[18] 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,

[18] This analysis assumes implicitly that any capital requirement the bank faces is not binding, at least not at all times; either the bank holds "excess" capital above a minimum requirement, or its capital temporarily drops below "well-capitalized" levels—a widespread phenomenon during the recent financial crisis. See, e.g., Berger, DeYoung, Flannery, Lee and Öztekin (2008) for recent empirical evidence on excess capital holdings by US banks.

$dD^*/dK = \partial D^*/\partial K + (\partial D^*/\partial L)\,(dL^*/dK)$, this can be rewritten as

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

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

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

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, $dL^*/dK > 0$. (So the sign of dL^*/dK is again determined by the direct effect, $\partial L^*/\partial K$.)

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 (2010) document that US banks sharply decreased lending, especially around the height of the crisis in the 4^{th} 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.[19]

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-

[19] Of course, as Ivashina and Scharfstein (2010) also note, there are competing explanations for an observed reduction in bank lending, notably a decrease in the demand for loans.

averse bank's equilibrium expected profits $E\left[\Pi^*\right]$ 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 fall in loans and a rise in deposits, so $dL^*/d\sigma_M^2 \leq 0$ and $dD^*/d\sigma_M^2 \geq 0$. It follows from (22) 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 $dE\left[\Pi^*\right]/d\sigma_M^2 \leq 0$.

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

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.

Indeed, recalling the bank's profit function $\Pi = (r_L - r)\,L + (r - r_D)\,D + (r - \tau)K$, it is clear that the bank may no longer by able to cover its cost of capital τ (i.e., the return required by its shareholders) under conditions of heightened funding uncertainty. This possibility becomes more likely if the cost of capital itself varies positively with the degree of funding uncertainty or risk aversion in the market (that is, $\tau(\lambda, \sigma_M^2)$ non-decreasing in both arguments). The bank may also become loss-making overall in the presence of fixed costs that need to be covered for it to be operational.

□ **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 $\Omega_D \equiv (\psi_D - 2\beta_D D) + \lambda\sigma_M^2 (L - D - K) = 0$. These can be solved, in the limit as $\sigma_M^2 \to \infty$, for

$$L^* = \frac{\frac{1}{2}(\psi_L + \psi_D) + \beta_D K}{(\beta_L + \beta_D)} \text{ and } D^* = \frac{\frac{1}{2}(\psi_L + \psi_D) - \beta_L K}{(\beta_L + \beta_D)}. \tag{23}$$

If the market for loans is very attractive (in that ψ_L is high), then this increases equilibrium loans, but also increases equilibrium *deposits* (recalling the loan-deposit synergies result from Proposition 1).[20] For sufficiently large ψ_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.[21]

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

[20] The condition for equilibrium deposits to be non-negative is $K \leq (\psi_L + \psi_D)/2\beta_L$. (See also note 8 above.)

[21] 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 (as long as its cost of capital τ is not too large).

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.[22]

Proposition 5 *In the presence of funding uncertainty $\sigma_M^2 > 0$, it is possible for either a bank's loan or its 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.[23]

While it seems 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 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 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 can provide an explanation for this apparent reduction in monetary policy effectiveness.

[22] So either $r_L^* > r_D^* > \bar{r}$ (deposits are loss-making, but loans are highly profitable) or $\bar{r} > r_L^* > r_D^*$ (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.

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

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 $\bar{r}$. In particular, recall the decomposition of the bank's funding rate into the central bank's policy rate plus a bank-specific spread. Thus a change in the central bank's rate leads, all else equal, to an identical change in a commercial bank's *expected* funding rate. The impact of 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 changes by 100 basis points, then loan and deposit rates change (approximately) by $100\rho_L$ and $100\rho_D$ basis points respectively.

Equilibrium 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:

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

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

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

The same approach on the deposits side gives

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

The equilibrium 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 σ_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 Π_{LL} and Π_{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 for loan demand and deposit supply respectively. Noting that $-\Pi_{LL} = -f_L'(L)\,[2 - \gamma_L(L)] > 0$ and $-\Pi_{DD} = f_D'(D)\,[2 - \gamma_D(D)] > 0$ yields the following result.

Proposition 6 *(i) If loan demand curvature γ_L and deposit supply curvature γ_D are both constant, then interest rate pass-through on loans ρ_L^* and deposits ρ_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 ρ_L^* and deposits ρ_D^* is decreasing in funding uncertainty σ_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 $\sigma_M^2 \to \infty$, money market exposure $M^* = 0$ and so 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, both rates of interest pass-through are zero in the limit.[24]

Although not completely general, Proposition 6 suggests that interest rate pass-through will typically be dampened when uncertainty on banks funding conditions is high.[25] Put differently, banks' pricing of loans and deposits becomes more rigid and less responsive to "shocks." In this sense, monetary policy becomes less effective

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

[25] 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 (for which $\gamma_L \leq 0$), but exceeds 100% with constant-elasticity demand (for which $\gamma_L > 1$). Finally, notice that interest pass-through in the risk-neutral case is constant only if the curvature parameter is constant, $\gamma_L(L) = \gamma_L$.

at influencing a bank's decision-making process—with market interest rates on loans and deposits completely frozen in the limiting case. Again, the same conclusions also hold in that increased risk aversion is typically associated with lower degrees of interest rate pass-through and less effective monetary policy.

Proposition 6 may thus 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.[26] Clearly, it would be interesting and useful for any future econometric research on pass-through to empirically test this prediction more formally.

Finally, observe that overall rate of pass-through to loan and deposit markets would be even lower if the initial pass-through from the central bank's policy rate to an individual bank's funding rate is itself also reduced by funding uncertainty.

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, and 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. In particular, I relax the underlying assumptions in turn by allowing the bank (i) to be exposed to multiple risks (as opposed to a single risk in form of funding uncertainty); (ii) to face competition in loan and deposit markets from other banks (as opposed to being a monopolist); and (iii) to engage in price-setting behaviour by choosing interest rates on its loans and deposits (as opposed to engaging in quantity-setting behaviour by committing to loan and deposit volumes).

□ **Extension 1**: **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 and deposits are themselves 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.[27] Nonetheless, under fairly mild conditions, the key insights from the benchmark model are

[26] 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.

[27] 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).

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 $\Omega_L \equiv E[\Pi_L] - \lambda \cdot cov(\Pi, \Pi_L) = 0$ and $\Omega_D \equiv E[\Pi_D] - \lambda \cdot cov(\Pi, \Pi_D) = 0$. Suppose now that the *marginal* risks on loans and deposits are given by

$$cov(\Pi, \Pi_L) = \lambda\left[\sigma_M^2 M + \upsilon_L(L, D)\right] \text{ and } cov(\Pi, \Pi_D) = -\lambda\left[\sigma_M^2 M - \upsilon_D(L, D)\right] \tag{28}$$

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 second-order conditions and stability conditions are satisfied.

A natural example that is a special case of this formulation has the bank's profit function $\Pi = (1-\theta)r_L L - r_D D - rM - \tau K$, 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).

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 here is equivalent to $\sigma_M^2 > \upsilon_{LD}(\cdot) \equiv \partial\upsilon_L(L, D)/\partial D$. 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 σ_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, higher funding uncertainty induces a bank with a high loan-to-deposit ratio to increase loans and decrease deposits (so both interest rates increase, at least in expectation), 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, that $E[\Pi_L] = \lambda \cdot cov(\Pi, \Pi_L)$ and $E[\Pi_D] = \lambda \cdot cov(\Pi, \Pi_D)$. 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 σ_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 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. Indeed, for large funding uncertainty σ_M^2, it is clear that the bank will avoid money market exposure similar to above, so its balance sheet constraint $L^* \approx D^* + K$ and interest rate pass-through on loans and deposits is again (approximately) zero.

□ **Extension 2: Competition between banks**. The setup underlying the benchmark model is also easily extended to Nash-Cournot competition between $n \geq 2$ risk-averse banks (which might also be offering differentiated savings and loan products).

Suppose that the inverse demand curve for loans from bank j is given by $r_L^j = g_L\left(L^j + \delta_L \sum_{k \neq j} L^k\right)$, where $g_L'(\cdot) < 0$ 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 $r_D^j = g_D\left(D^j + \delta_D \sum_{k \neq j} D^k\right)$, where $g_D'(\cdot) > 0$ 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 $\delta_L = 0$ and $\delta_D = 0$ or $n = 1$). The bank's profits are $\Pi^j = r_L^j L^j - r_D^j D^j - r^j M^j - \tau^j K^j$, where r^j is the uncertain funding rate (possibly bank-specific) on its money market exposure M^j, and $E[r^j] = \bar{r}$ and $var(r^j) = \sigma_M^2$ as above.

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

$$\max_{L^j, D^j} E\left[U\left(\Pi^j\right)\right] \text{ subject to } M^j = L^j - D^j - K^j, \tag{29}$$

where, with a slight abuse of notation, let $\Pi_L^j \equiv \partial \Pi^j / \partial L^j$ and $\Pi_D^j \equiv \partial \Pi^j / \partial D^j$. I continue to assume that the second-order conditions for the underlying risk-neutral case are satisfied, that is $\Pi_{LL}^j \equiv \partial \Pi_L^j / \partial L^j < 0$ and $\Pi_{DD}^j \equiv \partial \Pi_D^j / \partial D^j < 0$. Again, using Taylor expansions (or Stein's lemma) as in the benchmark model, the first-order conditions can be written as

$$\Omega_L^j \equiv E\left[\Pi_L^j\right] - \lambda \cdot cov\left(\Pi^j, \Pi_L^j\right) = 0 \tag{30}$$

and

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

Moreover, it is easy to check that $cov\left(\Pi^j, \Pi_L^j\right) = \sigma_M^2 M^j$ while $cov\left(\Pi^j, \Pi_D^j\right) =$

$-\sigma_M^2 M^j$, 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. In particular, each bank's marginal risks move in opposite directions, $cov\left(\Pi_L^j, \Pi_D^j\right) = -\sigma_M^2 < 0$, again regardless of whether the bank is a borrower or lender in the interbank market. Thus, loan-deposit synergies exist at the level of an individual bank, $\partial L^j/\partial D^j \in (0,1)$ and $\partial D^j/\partial L^j \in (0,1)$, just as in Proposition 1.

Summing the first-order conditions yields that, in symmetric Nash-Cournot equilibrium, in which each bank has the same amount of equity capital $K^j = K/n$ (and letting $L^j = L/n$, $D^j = D/n$, and $M^j = M/n$),

$$\widetilde{\Omega}_L \equiv E[\widetilde{\Pi}_L] - \lambda\sigma_M^2 M = 0 \text{ and } \widetilde{\Omega}_D \equiv E[\widetilde{\Pi}_D] + \lambda\sigma_M^2 M = 0, \tag{32}$$

where $\widetilde{\Pi}_L \equiv \sum_{j=1}^n \Pi_L^j$ for loans and $\widetilde{\Pi}_D \equiv \sum_{j=1}^n \Pi_D^j$ for deposits respectively. These two conditions correspond to (6) and (7) above, and together implicitly define equilibrium *total* loans L^* and deposits D^* by all $n \geq 2$ banks. I assume that the industry-level marginal profits on loans and deposits, $\widetilde{\Pi}_L$ and $\widetilde{\Pi}_D$, are both also downward-sloping, that is, $\widetilde{\Pi}_{LL} \equiv \partial\widetilde{\Pi}_L/\partial L < 0$ and $\widetilde{\Pi}_{DD} \equiv \partial\widetilde{\Pi}_D/\partial D < 0$. This ensures that the industry-level equilibrium conditions from (32) are well-behaved in that "aggregate" second-order and stability conditions are satisfied.

Under these mild conditions, the loan-deposit synergies at the level of an individual bank carry over to the industry-level, that is $\partial L^*/\partial D \in (0,1)$ and $\partial D^*/\partial L \in (0,1)$. The reason is that industry-level marginal risks are also negatively correlated, $cov(\widetilde{\Pi}_L, \widetilde{\Pi}_D) = -n^2\sigma_M^2 < 0$. Again, since both cross-effects lie within the unit circle, the overall equilibrium is unique and stable. Moreover, in symmetric equilibrium, each bank chooses the same loan and deposit volumes, so they are either all borrowers or all lenders in the money market, and respond to changes in funding uncertainty in the same way.

The insights from the benchmark model thus carry over to such richer settings with competition between banks. To see why, observe that the arguments that led to Propositions 2 to 5 do not depend on the details of the profit function, but only rely on basic second-order conditions and stability conditions being satisfied. So the same techniques used for the benchmark model can be applied to the industry-level equilibrium conditions $\widetilde{\Omega}_L = 0$ and $\widetilde{\Omega}_D = 0$ to show that the above results continue to hold with competition between banks.

Finally, the degree of interest rate pass-through is, of course, affected by changes in market structure. However, the general tendency for funding uncertainty to dampen pass-through is preserved in that Proposition 6 applies, in exactly the same way, to this setting.[28] For example, with homogeneous products and linear demand and supply schedules ($r_L = \alpha_L - \beta_L L$ and $r_D = \alpha_D + \beta_D D$), it is easy to check that equilibrium interest rate pass-through

$$\rho_L^* = \rho_D^* = \frac{n}{(n+1) + \lambda\sigma_M^2\left(\dfrac{1}{\beta_L} + \dfrac{1}{\beta_D}\right)}. \tag{33}$$

Clearly, pass-through rates on loans and deposits are decreasing in funding uncertainty, and both tend to zero as funding uncertainty becomes large (thus confirming parts (ii) and (iii) of Proposition 6). Note also that interest rate pass-through increases with competition (that is, in the number of banks) in this example, consistent with recent evidence for the Eurozone (see, e.g., van Leuvensteijn, Kok Sørenson, Bikker and van Rixtel, 2008).

□ **Extension 3**: **Price-setting behaviour**. 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 a bank as choosing prices—that is, interest rates—on deposits and loans. I show that the results for the benchmark model are exactly the same with price-setting behaviour, and the insights also extend to a model of Nash-Bertrand competition between banks.

Consider a single bank that faces a demand for loans $L = f_L^{-1}(r_L)$, supply of deposits $D = f_D^{-1}(r_D)$, and maximizes expected utility by choosing interest rates:

$$\max_{r_L, r_D} E\left[U\left(\Pi\right)\right] \text{ subject to } M = L - D - K, \tag{34}$$

where I continue to assume that the second-order conditions for the underlying risk-neutral case are satisfied. Using the same arguments as in the benchmark case, the two first-order conditions can be written as $\overline{\Omega}_L \equiv E\left[\overline{\Pi}_L\right] - \lambda \cdot cov\left(\Pi, \overline{\Pi}_L\right) = 0$ and $\overline{\Omega}_D \equiv E\left[\overline{\Pi}_D\right] - \lambda \cdot cov\left(\Pi, \overline{\Pi}_D\right) = 0$ (where $\overline{\Pi}_L \equiv \partial\Pi/\partial r_L$ and $\overline{\Pi}_D \equiv \partial\Pi/\partial r_D$). On the loans side, it is easy to check that $E\left[\overline{\Pi}_L\right] = L + \left(r_L - \bar{r}\right)/f_L'(L)$ and

[28] For part (i) of Proposition 6, define $Z_L \equiv (L/n)\left[1 + \delta_L(n-1)\right]$, so the curvature of loan demand $\xi_L(Z_L) \equiv -Z_L g_L''(Z_L)/g_L'(Z_L)$ in symmetric equilibrium (where $L^j = L/n$). Demand curvature is constant if $\xi_L(Z_L) = \xi_L$ and linear if $\xi_L = 0$. Similarly, on the deposit side, define $Z_D \equiv (D/n)\left[1 + \delta_D(n-1)\right]$ so supply curvature $\xi_D(Z_D) \equiv Z_D g_D''(Z_D)/g_D'(Z_D)$ in symmetric equilibrium. (Note also that industry-level marginal profits on loans are downward-sloping $\widetilde{\Pi}_{LL} < 0$ if and only if $\xi_L(Z_L) < \left[2 + \delta_L(n-1)\right]$, and, for deposits, $\widetilde{\Pi}_{DD} < 0$ if and only if $\xi_D(Z_D) > -\left[2 + \delta_D(n-1)\right]$. Similar to the benchmark model, loan demand is not too convex and deposit supply is not too concave.)

$cov\left(\Pi,\overline{\Pi}_L\right)=\sigma_M^2 M/f_L'(L)$. It follows that the equilibrium condition for loans

$$\overline{\Omega}_L \equiv \left[L+\left(r_L-\bar{r}\right)/f_L'(L)\right]-\lambda\sigma_M^2 M/f_L'(L)=0. \tag{35}$$

Observe that this is equivalent to the benchmark model since $\overline{\Omega}_L=\Omega_L/f_L'(L)$, and so $\overline{\Omega}_L=0$ if and only if $\Omega_L=0$. In other words, for any level of funding uncertainty, the bank chooses exactly the same loan rate and loan volume as in the benchmark model. The same analysis and conclusion also hold on the deposits side ($\overline{\Omega}_D=0$ if and only if $\Omega_D=0$), which already implies that the results from Propositions 1 to 6 apply in *exactly* the same way under price-setting behaviour.

These results can also be extended to settings with competition between price-setting banks. For example, consider a differentiated products Nash-Bertrand model in which bank j's loan demand $L^j=h_L\left(r_L^j-c_L r_L^{-j}\right)$ and deposit supply $D^j=h_D\left(r_D^j-c_D r_D^{-j}\right)$ (where $h_L'(\cdot)<0$ while $h_D'(\cdot)>0$, $r_L^{-j}\equiv\sum_{k\neq j}r_L^k$ and $r_D^{-j}\equiv\sum_{k\neq j}r_D^k$ reflect the interest rates set by other banks, and $r_L^j-c_L r_L^{-j}>0$ and $r_D^j-c_D r_D^{-j}>0$). For simplicity, I here assume that loan demand and deposit supply are both linear, so $h_L''(\cdot)=h_D''(\cdot)=0$.

Each bank solves $\max_{r_L^j,r_D^j} E\left[U\left(\Pi^j\right)\right]$ subject to its balance sheet constraint $M^j=L^j-D^j-K^j$. Using the same arguments as in the benchmark case, bank j's first-order conditions can be written as $\overline{\Omega}_L^j\equiv E[\overline{\Pi}_L^j]-\lambda\cdot cov(\Pi^j,\overline{\Pi}_L^j)=0$ and $\overline{\Omega}_D^j\equiv E[\overline{\Pi}_D^j]-\lambda\cdot cov(\Pi^j,\overline{\Pi}_D^j)=0$ (where $\overline{\Pi}_L^j\equiv\partial\Pi^j/\partial r_L^j$ and $\overline{\Pi}_D^j\equiv\partial\Pi^j/\partial r_D^j$). With a linear demand-supply structure, second-order conditions for the underlying risk-neutral benchmark (with $\lambda=0$) are always satisfied, and it is also easy to check that the marginal risks $cov(\Pi^j,\overline{\Pi}_L^j)=\sigma_M^2 M^j h_L'(\cdot)$ and $cov(\Pi^j,\overline{\Pi}_D^j)=-\sigma_M^2 M^j h_D'(\cdot)$, respectively.

Summing the first-order conditions yields that, in symmetric Nash-Bertrand equilibrium, in which each bank sets the same interest rates on loans and deposits, $r_L^j=r_L$ and $r_D^j=r_D$ (so also $L^j=L/n$, $D^j=D/n$, $K^j=K/n$, and $M^j=M/n$),

$$\widetilde{\overline{\Omega}}_L\equiv\left[L+n(r_L-\bar{r})h_L'(\cdot)\right]-\lambda\sigma_M^2 M h_L'(\cdot)=0 \tag{36}$$

and

$$\widetilde{\overline{\Omega}}_D\equiv\left[-D+n(\bar{r}-r_D)h_D'(\cdot)\right]+\lambda\sigma_M^2 M h_D'(\cdot)=0. \tag{37}$$

These two industry-level conditions again correspond to (6) and (7) from the benchmark model, and together implicitly define equilibrium *total* loans L^* and deposits D^* by all $n\geq 2$ price-setting banks. With the linear-demand supply structure, loan-deposit synergies exist at both the level of an individual bank, and at the industry-level. Once again, the same techniques used for the benchmark model can be applied to the industry-level equilibrium conditions $\widetilde{\overline{\Omega}}_L=0$ and $\widetilde{\overline{\Omega}}_D=0$ to show that Propositions 2 to 5 continue to hold with competition. Moreover, interest rate pass-through is dampened under funding uncertainty in the sense corresponding to parts (ii) and (iii) of Proposition 6.

9 Concluding comments

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. Although there is a sizeable literature on models of banking competition, existing contributions do not incorporate the role of funding uncertainty in money markets and the resulting loan-deposit synergies identified here. Moreover, to the best of my knowledge, this paper is the first to examine interest rate pass-through in a setting with risk-averse banks, and to identify the possibility of deposits turning into a "loss leader" due to funding uncertainty.

The main results are that, in banking systems with high loan-to-deposit ratios, increased funding uncertainty tends to make banks and their shareholders worse off, and also reduces the welfare of borrowers due to higher loan rates and reduced lending volumes. By contrast, savers may end up benefitting substantially from more intense competition for retail deposits. The analysis can also help explain why banks with a strong deposit base appear to have done better throughout the recent financial crisis, and why other banks such as Royal Bank of Scotland are now aiming to reduce their loan-to-deposit ratios back towards 100%. Finally, monetary policy becomes less effective in the sense that 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.

An advantage of the model presented here is that it delivers a surprisingly rich set of implications using a simple framework that is driven solely by a volatility shock in form of increased uncertainty over banks' funding conditions. The basic mechanism—banks substituting away from money market funding to less risky sources of finance—seems fairly robust to changes in model specification such as competition between banks and multiple sources of uncertainty (as shown in the extensions). However, thinking about bank behaviour and its implications for the economy is a complex task (especially in the context of a financial crisis), and the model admittedly abstracts from many important issues.

For example, the present analysis has been based on the premise that commercial banks are risk-averse—or at least that they turn risk-averse in the context of a financial crises. As noted above, this assumption can be backed up with various theoretical arguments and has some empirical support, but it is, of course, also somewhat restrictive. An alternative approach would be to generate a concern for risk management along the lines of Froot and Stein (1998). They assume that a bank's cost of obtaining non-deposit external finance is an increasing and (strictly) convex function of the amount of funds raised. A direct way of mapping this approach into the present analysis is to assume the bank is risk-neutral but that its cost of interbank market borrowing is given by $C(M) = rM + (w/2)M^2$, where $M \geq 0$ and $w > 0$ is a measure of the severity of the external finance premium. The bank's problem then is to $\max_{L,D} E[\Pi] = r_L L - r_D D - \tau K - C(M)$, subject to the balance sheet constraint $M = L - D - K$. It is not difficult to see that the first-order conditions for this problem are identical to (6) and (7) in the benchmark model (by setting $w \equiv \lambda\sigma_M^2$). It follows immediately that Propositions 1–3, 5 and 6 apply in *exactly* the same way after replacing "funding uncertainty" with "external finance premium." An increase in the latter can similarly be interpreted as a representation of tighter funding conditions.[29]

Relatedly, the benchmark model identifies increased funding uncertainty with higher volatility of the funding rates obtained on unsecured term loans in the interbank market. This approach is consistent with Taylor and Williams' (2009) evidence of increased interest-rate volatility in measures such as three-month LIBOR rates. Another approach would be to consider funding uncertainty over quantities rather than prices. Such quantity-based uncertainties may arise, for example, due to credit rationing in interbank markets, and may be particularly important when considering very short-term financing. Recent empirical evidence from Afonso, Kovner and Schoar (2011) suggests that *both* price- and quantity-based uncertainty played important roles in the U.S. overnight interbank market during 2008/9. Their analysis particularly emphasizes credit rationing and the problem of rolling over interbank debt on a day-to-day basis. It would be interesting and potentially instructive for future research to combine both types of uncertainty into a single model.

Finally, the present paper has abstracted from general-equilibrium considerations across funding markets, as well as from integrating elements of asymmetric information between banks into the modelling approach. Future work might combine the detailed equilibrium analysis of bank behaviour in loan and deposit markets presented here with a more general setup that explicitly takes into account the microstructure of interbank markets. More research into why funding conditions in money markets became so volatile in the first place is clearly also still needed.

[29] Of course, this is not the whole story in Froot and Stein (1998), since their multi-period approach involves a wealth shock that leads to *ex post* adjustments to the quantity of external borrowing, M. Because of the convexity assumption, these ex post fluctuations increase a bank's *expected* funding costs and thus generate more risk-averse behaviour from an ex ante point of view. I expect that *jointly* modelling (i) an increase in the severity of the external finance premium (that is, higher w), as well as (ii) an increase in the ex post volatility of the funding requirement (that is, higher $var(M)$) would exacerbate the results from the present analysis without affecting their qualitative nature.

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