Understanding the Current Credit Crisis:

Maturity mismatch and structured credit illiquidity

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Paper outline.

1. Introduction and motivation.

   The current financial crisis has created extraordinary stresses in credit and money markets, affecting many instruments not just the sub-prime mortgage backed securities where the crisis originated. Credit spreads have jumped to extraordinarily high levels and, alongside these price falls, the trading volumes of corporate bonds, leveraged loans and structured credit securities have all slumped. Similar illiquidity has emerged in short term money markets, with collapse of lending volumes and a sharp rise in reported money market rates such as LIBOR compared to expected policy rates.

   This paper argues that maturity mismatch is the major explanation of these developments. This maturity mismatch has then undermined bank funding and providing one of the major triggers of the subsequent credit squeeze that has undermined the global economy. The unfolding of the current crisis has been due in large part to problems of structured credit illiquidity limiting the supply of credit *not* just to wider credit problems undermining the structured credit and money markets.

   This mechanism is described in Brunnermeier (2008), Brunnermeier et. al. (2009), and Gorton (2009) and in Milne (2009). The argument made here, together with the supporting tables and charts, follow Milne (2009). Illiquidity in money markets has been driven by a combination of maturity mismatch and a lack of easily acceptable collateral. Since the loss of confidence in structured credit securities is long lasting so is the illiquidity of money markets.

This paper also argues that, because of the reliance of banks on collateralised wholesale borrowing as a source of funding, the traditional role of central banks as 'lender of last resort' providing loans to banks who cannot easily borrow in the money markets, can no longer be expected to bring uncollateralised lending rates back in line with good collateral lending rates or with expected monetary policy rates.

The major central banks, the Federal Reserve, the European Central Bank and the ECB, have acted as lenders of last resort, responding to these illiquidity problems, since they first emerged on August 9th 2007, by substantially increasing their lending to banks, mainly through collateralised repo loans at both overnight and term maturities. After the global bank run that followed the September 15th, 2009 failure of Lehman there was an extraordinary expansion of central bank balance sheets and a shift to direct intervention in some credit markets. Total Federal Reserve assets and liabilities more than doubled to over $2000bn in just a few weeks.[1] The various Fed liquidity facilities expanded dramatically, including some $380bn in short term and term repo loans, and $790bn in other credit of different kinds including loans to broker dealers and programs to support the commercial paper market. Central bank balance sheets have expanded yet further as first the Federal Reserve and then the Bank of England have adopted policies of 'quantitative easing', expanding their own balance sheet to purchase government bonds and other securities.

Central bank supply of reserves and credit was necessary, in order to avoid even greater money and credit market stresses. But similar market dislocations have arisen in other financial crises, for example following the Russian default of 1998, but in these previous episodes heighted credit and money market spreads lasted only a few days or weeks before subsiding. This paper further argues that central banks have had only a limited impact on credit and money market stresses in the recent crisis, because of the limits on their own ability to accept credit risk. This is why the current dislocations continued so long and been relatively unresponsive to central bank actions.

There will be continuing debate about the central bank response to the crisis. Did they do too little? Could the magnitude of these dislocations have been reduced by central banks supplying loans and reserves on an even greater scale than actually occurred, for example through a much greater relaxation of collateral requirements for repo lending? Or, to the contrary, have central banks overreacted, protecting banks from the consequences of their own portfolio decisions, thus weakening incentives to control both liquidity and credit risks and laying the seeds for even greater dislocation in the future? Finally can new liquidity regulations, being developed by the Basel Committee on Banking Supervision and by national regulators and requiring banks to hold greater amounts of liquid assets such as Treasury securities, help restore liquidity to short term money markets; or are these latest policy response misplaced? This paper offers some preliminary conclusions on these further questions.

[1] The weekly Federal Reserve Balance sheet is reported in the downloadable H.4.1 statistical release.

The paper is organised as follows. Section 2 presents the key puzzle – the low level of pricing and illiquidity of senior structured credit securities where the underlying default risk is very low – on which this paper focuses. Section 3 argues that maturity mismatch, together with agency costs on the buy side of the market, explains this illiquidity. Section 4 then reviews some of the policy issues discussing why traditional 'lender of last resort' has not resolved the problems of market illiquidity. Section 5 summarises and concludes. An appendix (currently incomplete) develops a supporting formal model.

2. The majority of structured credit securities are safe from default.

A key point, one that is not as widely appreciated as it should be, is that most structured credit securities are almost entirely free of default risk even in the event of a major economic downturn.

We can begin with some estimates of the end-2007 stock of structured credit products (all tables from Milne (2009)):

Table 2.2. Approximate magnitudes of the European and US structured credit market

	Fourth quarter of 2007, outstanding		
	Europe	US	Total
			$ trillion
Agency RMBS		5.9	5.9
Sub-prime RMBS		0.8	0.8
Other RMBS	1.0	0.5	1.5
ABS	0.2	1.8	2.0
CMBS	0.2	1.0	1.2
CDO	0.4	1.1	1.5
Total	1.8	11.1	12.9
Total non-agency	1.8	5.2	7.0

Sources: ESF, SIFMA. US CMBS and CDO are author's estimates of stock outstanding based on published data for issuance flow. US ABS excludes $1trillion of 'other', mostly government guaranteed ABS. European data converted to dollars using end-2007 exchange rate of $1=€0.6794. CDO include leveraged loan, bond, and synthetic structures.

As the right-hand column of this table reveals, sub-prime residential mortgage backed securities were only a relatively small part of the total issue of structured credit securities. Even if we exclude the 'agency' RMBS, i.e. the mortgage backed securities issued and guaranteed by US government sponsored enterprises such as Fannie Mae and Freddie Mac, there was a total stock of structured credit products was around$7 trillion dollars, nearly twice as large for example as the issue of US federal government debt.

Other important categories of structured product are ABS (securitisations of consumer loans such as credit cards, and vehicle loans as well as other categories such as manufactured housing loans, vehicle loans and some small business loans), CDOs ('collateralised debt obligations' an umbrella term referring to all forms of securitisations of traded debt such as corporate bonds, tradable syndicated loans, corporate credit default swap. Re-securitisations of tranches of residential and

commercial mortgage backed securities ('ABS-CDOs') are excluded from this table to avoid double counting.

A large proportion, at least 70%, of the outstanding stock of these structured products were senior tranches obtaining AAA ratings. The ratings for these senior tranches were reasonable, reflecting the fact that default rates would have to rise to implausibly high levels in order trigger default. The following table provides an illustration, one particular sub-prime MBS issued by Countrywide Financial in September of 2006.

Table 4.1. Securities sold to investors by Countrywide ABS 2006-19

Notes	Par values	Outstanding, December 2008	Coupon	Ratings by:	
	$ mn	%	Libor + basis points	Moody's	S&P
1-A	259.8	56	14	Aaa	AAA
2-A-1	186.5	17	6	Aaa	AAA
2-A-2	182.2	100	16	Aaa	AAA
2-A-3	42.4	100	25	Aaa	AAA
M-1	53.6	100	33	Aa1	AA+
M-2	44.6	100	34	Aa2	AA
M-3	17.1	100	35	Aa3	AA-
M-4	19.8	100	40	A1	A+
M-5	17.6	100	42	A2	A
M-6	12.6	100	50	A3	A-
M-7	13.5	100	90	Baa1	BBB+
M-8	8.6	100	120	Baa2	BBB
M-9	11.7	100	250	Baa3	BBB-
Total	870				

This structure was backed by some $900mn of mortgages issued to some 4,794 mortgage borrowers. The $870mn of securities offered to investors were all investment grade. The remaining $30mn consisted of a speculative grade and a retained equity tranche not offered to investors.

This structure, like many others, issued different types of senior AAA security. The security labelled 1-A is secured on one loan pool ('pool 1'). The others, labelled 2-A-1, 2-A-2 and 2-A-3 are secured on a second loan pool containing different mortgages ('pool 2'). 2-A-1 and 2-A-2 are 'super-senior' tranches regarded as better quality than AAA, because they have a claim that is senior to the AAA tranche 2-A-3.

Much attention has been paid to the problems with the mezzanine tranches of these and similar structures (for the securities M1-M9 in the Countrywide ABS 2006-19

example shown here). AAA tranches have remained safe and only in very few cases have been downgraded (press reports of widespread downgrading of AAA tranches refer to the unsound restructured ABS-CDOs and CDO[2] not to loan backed securities such as this example).

There have been many downgrades and some defaults amongst the *mezzanine* tranches of US RMBS structures, the tranches rated less than AAA. The mezzanine tranche performance during the US housing market downturn has been much worse than investors anticipated. This is for two main reasons. In part it was due to widely reported problems with quality of the loans purchased for inclusion inside US residential mortgage backed securities. The originators of these loans often retained little or no financial interest in these loans, so the incentives to maintain credit standards were relatively weak.[2] This was less of a problem for Countrywide securitisations such as this example than for many others. This is because Countrywide did most of their own origination and relied relatively less than other sub-prime MBS issuers such as Lehman Brothers, Bear Stearns, or Merrill Lynch, on purchasing securities from mortgage brokers.

The performance of the mezzanine tranches was also disappointing. Investors did not appreciate the degree of correlation of loan default and loan losses and therefore the exposure of these mezzanine tranches in the event of a nationwide housing downturn. With the benefit of hindsight, it appears that investors greatly exaggerated the diversification protection offered by these securitisation structures. They also failed to realise that loss given default would be far higher for a structured credit security of a given credit rating than for an equivalently rated corporate bond.As a result they overpaid for the riskier securities.[3]

This paper is not concerned with the problems of these mezzanine tranches or other relatively risky structured credit securities that have exhibited high levels of underlying credit impairment during the credit crisis. The focus here is instead on the close to $5 trillion of safe AAA structured securities. A key point to make here is that almost all these AAA tranches really are extremely secure. Loan losses in the Countrywide ABS 2006-19 example shown here would have to rise to around 35% of the original $900mn in order for there to be an AAA default. At end-December 2008 loan losses were running at less than 4% (foreclosures of 20% and a loss given default of 20%). Even on pessimistic projections aggregate foreclosures of sub-prime look unlikely to exceed 50% of total lending and loss given default to rise above 30%, which would still only generate pool losses of 15% of the original lending. The

[2] See Muolla and Padilla (2008) for a detail account of the problems in the sub-prime securitization process. Demyanyk and Hermert (2009, forthcoming) provide econometric evidence for a declining sub-prime mortgage underwriting standards during the years of the lending boom between 2002 and 2006, masked by high house price appreciation.

[3] See Brennan, Hei and Poon (2009) for an analysis of how 'pricing to rating' i.e. to expected default rates, without allowance for correlation and systematic risk, supported excess profits in structured finance.

outcome has been similar for other AAA structured securities which remain at little risk of default, even in a much more adverse economic situation than any one is currently envisaging. And even if there is default, loss given default will remain low because these are the most senior securities.

This creates a puzzle. Despite their low risk of credit default, the market for the issue of these AAA securities has been closed since August of 2007 and their 'mark to market' prices have fallen sharply, typically to 85 or 80 percent of par and sometimes even lower. Once indication of these declines are in the prices of the the various ABX index, reported by Markit. The ABX is a traded index of the prices of 20 underlying sub-prime mortgage backed securities. The AAA versions of this index are referenced to 20 of the most widely held AAA tranches of US sub-prime mortgage backed securities. As with the Countrywide example presented here, the underlying default risk of these securities is very close to zero. Yet the AAA ABX indices for 2006 and 2007 issues are trading at between 80 and 85 per cent of par.

This is the central problem addressed in this paper. The prices of these securities fallen far below any reasonable assessment of their fundamental value. Trading has ceased. Why has this happened and why have central bank responses failed to correct this mispricing and illiquidity?

3. Maturity mismatch as an explanation of illiquidity

There are two widely tendered explanations of the illiquidity of senior structured credit securities. The first is that it is due to a 'lemons' problem. The second that it is due to maturity mismatch.

According to the lemons argument would be purchasers are unable to distinguish the quality of structured credit securities, rather as in the original Akerlof analysis of the sale of second hand cars. They realise that a proportion of these securities are unsound but cannot determine which of them. This lemons problem was only widely appreciated once the US housing market weakened. This then appears to explain why, beginning in the summer of 2007, the pricing of structured credit securities fell below levels based on fundamentals and the volume of trading collapsed.

This lemons argument does not stand up to close scrutiny. Adverse selection does affect the primary markets for the issue of new securities, especially for equity IPOs. Indeed this is the main explanation of why issuers seek the support of investment banks for their equity IPOs and are willing to pay relatively large issue fees. Adverse selection is much less of a problem for fixed income securities. In particular there is a wealth of information available on the underlying loan pool performance of structured credit securities, such as the Countrywide ABS-2006-19, more information even than is available on corporate bond issuers. As the previous section argues there is no

material risk of default of the safer senior AAA tranches. Their illiquidity cannot be explained by adverse selection.

A better explanation of the standstill and underpricing of structured credit products is maturity mismatch, the fact that most investment in these products was financed using short term repo and commercial paper funding. This section develops this argument. The key point is that a large proportion of these securities were held by banks and financed short term using repo and ABCP.

Establishing this point is not entirely straightforward. While there are some statistics for the total outstanding stock of structured credit products (Table 2.1) there is very little direct information on which institutions were holding this paper and on how these positions were financed. The International Monetary Fund has reported some broad estimates based on consultation with (IMF 2008). Similar casual evidence of large bank holdings comes from a number of press reports and the account of industry practitioners. Some cross-check can be provided by looking at bank accounting statements which confirm that banks held large portfolios of structured credit securities: some in off balance sheet special purpose vehicles (known as conduits and SIVs which held a total of perhaps around $1trillion of structured paper o f which $650bn was rated AAA), more often in trading portfolios financed out using repo, or held on balance sheet as available for sale financial instruments that could be sold or used as collateral to raise short term funds.

While an element of judgement is involved it seems safe to conclude that Banks world wide were holding around at least $3 trillion of safe senior AAA structured credit products of Table 2.1, with a large proportion of the remaining senior tranches held by insurance companies.

Until the crisis broke these securities were trading relatively freely at prices largely determined by their credit ratings and could be used for collateralised borrowing with haircuts of around 5%. They were what Gorton and Pennachi (1990) calls ‘informationally insensitive’ i.e. their returns were so predictable that there was no profitable opportunity for speculators to use them for trading, based either on information about underlying fundamentals or about the expectations of other investors. Gorton and Pennachi (1990) argue that such ‘informational insensitivity’ is the defining feature of bank debt and Gorton (2009) argues that banks, by securitising, were meeting an increasing demand for such informationally insensitive assets, resulting from the increased demand for cash collateral in derivative trading.

Both Calomoris (2008) and Gorton (2009) draw parallels between the 19th century panics in US banking and the 2007 crisis. In recent years a large share of the financing of credit to both corporate and household borrowers – especially for mortgages, for the debt financing of private equity deals, and in the US for other forms of asset backed securities – was raised from loan backed tranched securities.

Much of this ‘parallel’ banking (a better phrase than ‘shadow’ banking since the loans themselves were much better documented than traditional bank loans) was funded not through bank deposits but through collateralised repo and ABCP borrowing. What then occurred was a run on the banking system, similar to the bank runs of the late 19th and early 20th century, in which wholesale borrowers lost confidence in these structures and withdrew funding.

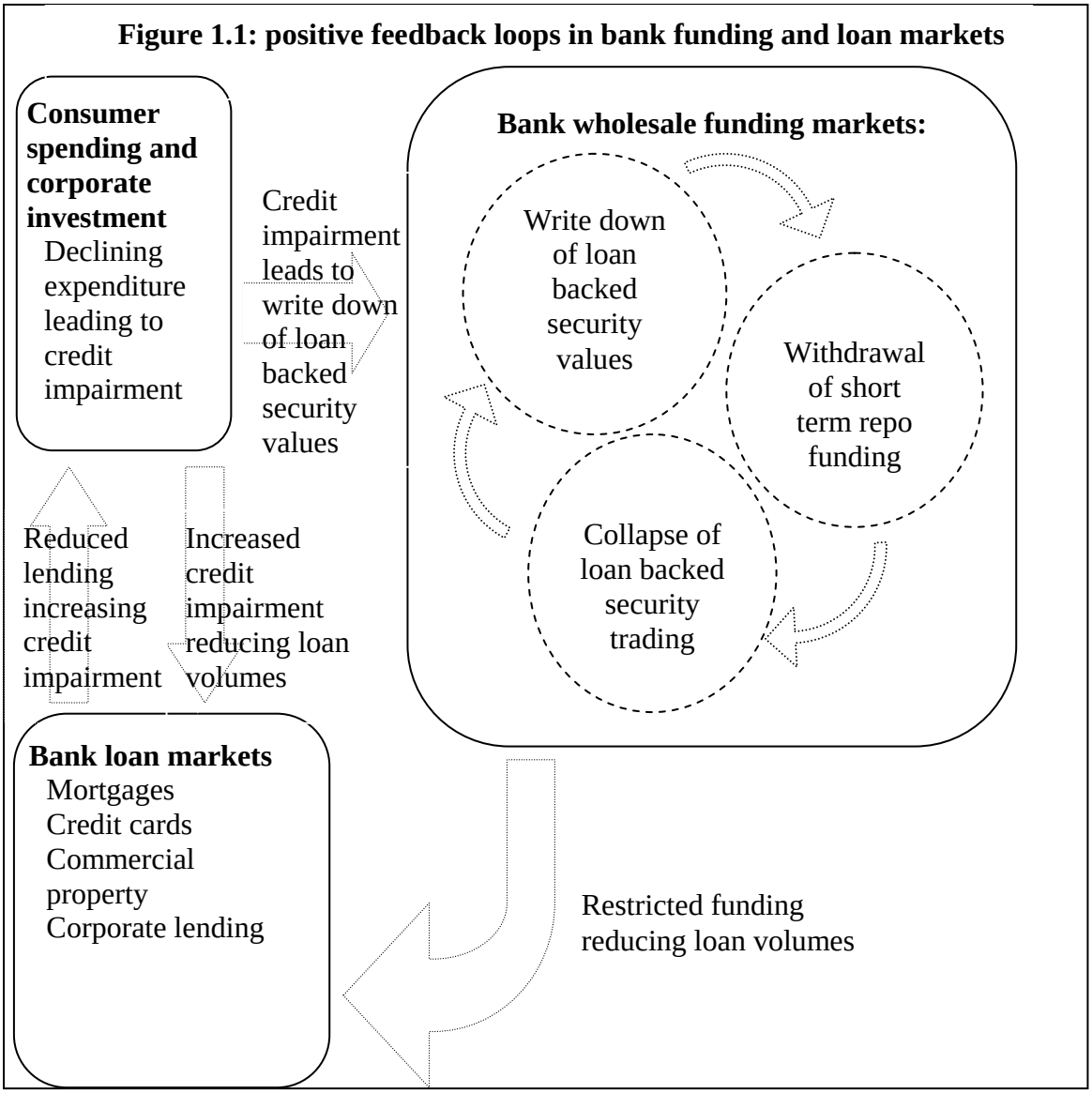
The trigger for this run were increasing doubts about the repayment of sub-prime mortgage triggered a feedback loop. Banks sought to reduce their exposure to US subprime mortgage backed securities, even to the senior securities for which the risk of default was remote. With relatively few buyers of these securities there was insufficient liquidity to be able to execute these trades and selling prices fell sharply and became extremely volatile (See Perraudin and Wu (2008) Figure [] for an illustration). The price falls and the associated increases in haircuts in turn reduced available financing and led to banks seeking to reduce their exposure further.

This impacted not just subprime related securities but also the entire range of other structured credit products, with similar if less marked declines of liquidity and recorded pricing in other private label MBS, ABS, CLOs and other structured credit products. As Gorton (2009) points out, the price declines of these products, and of the AAA tranches of sub-prime MBS moved sharply and, critically, did not move closely in line with the pricing of the lower tranches of sub-prime MBS (as measured by the ABX BB and BBB indices) but rather in parallel with each other, reflecting withdrawal of funding from short-term structured credit products rather than underlying credit fundamentals..

Figure 1.1, from Milne (2009) Chapter 1, illustrates. The feedback loop on the top right hand side of this figure represents the impact of increasing doubts about the repayment on mortgage backed and other structured credit securities on the availability of bank funding, which in turn reduced the availability of bank credit and amplified the credit squeeze.

There is a further feedback loop illustrated on the left of this figure, in which reduced bank credit availability increased prospective defaults on bank loans, eroded bank capital, and hence further inhibited bank lending. This further mechanism became especially powerful in the autumn of 2008. It is not however the subject of this paper.

Figure 1.1: positive feedback loops in bank funding and loan markets



This price collapse in structured credit markets then in turn impinged on money markets for two related reasons. MBS and other structured securities were an important collateral for money market borrowing. Without this collateral banks were forced to turn to relatively expensive uncollateralised borrowing or, more often, to sell assets further contributing to price declines. At the same time the funding problems created doubts about bank liquidity and (ultimately) bank solvency pushing up margins on uncollaterlalised borrowing and leading to a substantial contraction of maturities in the interbank market. By September and October these doubts led to an almost complete collapse of interbank lending.

This mechanism is distinct from, but often confused with, the mispricing and losses on the riskier tranches of subprime mortgage backed securities, ABS-CDOs and CDO^2 , the restructured products that were exposed to very substantial credit losses as the US housing market weakened and mortgage defaults rose. The lowest quality

mezzanine ABS-CDOs were trading at about 6 cents in the dollar at end-2008, reflecting the expectation that repayments of both interest and principal on these securities will be extremely low.

The reason for the price collapse of AAA tranches of vanilla MBS, ABS and CLOs are quite different. At end-2008, these were typically trading (where trades took place at all) at 80-85 cents in the dollar or less and by March 2009 prices had fallen even further. But this pricing does not reflect fundamentals. Take for example the riskiest 2006 sub-prime securities. These are typically heading for aggregate foreclosures of around 30-40% with loss given default of 25-35%, so aggregate losses will end up around10-15%. Even on relatively pessimistic scenarios the aggregate portfolio losses on all but a few structures will be less than 20%. All the AAA tranches, often about 75% of the underlying collateral pool will still be repaid.

This illiquidity had severe consequences. Prices trading at well below fundamentals and a shortage of acceptable collateral created the liquidity problems which, in March 2008, triggered the failure of Bear Stearns and its eventual purchase for $2 per share (later increased to $10) by J P Morgan. While there had been losses in two credit investment funds run for customers by Bear Stearns, the firm itself had not lost large amounts of money. It had relatively little direct exposure to the riskier structured credit exposures, such as ABS-CDOs or mezzanine sub-prime tranches. But Bear Stearns was in a weak position because it was highly leveraged with no strong deposit base and a focussed on activities which relied on raising short term finance in repo markets. Market participants anticipated the fact that Bear Stearns might face liquidity difficulties and this in turn caused them to limit their exposures to the firm. Bear Stearns should have raised substantial amounts of new capital in order to weather these problems, but it failed to do so.

The same problem of illiquidity also resulted in the closure of the markets for mortgage and consumer loan backed securitisations – and thus led directly to the failures of Northern Rock in the UK (after the botched announcement of public sector lending to bridge their financing gap triggered a retail run) and of Countrywide Financial (which faced similar problems to Northern Rock but avoided failure through an acquisition by Bank of America.)

These feedback loops worsened considerably in September and October of 2008 when, following the failure of Lehman Brothers and of AIG, the ‘run’ spread from structured credit securities to bank balance sheets. The combination of a deteriorating macroeconomic outlook together with the failure of Lehman (which was an unavoidable outcome, not a policy choice, due to the constitutional limitations on the ability of either the US Treasury or the US Federal Reserve to provide financial support to a failing institution, see for discussion) which reminded investment and commercial debt holders that their claims were indeed risky, meant that no bank perceived as risky could borrow any more from money markets, either from bank or non-bank lenders.

4. The policy responses

As argued by Calomiris (2008) and Gorton (2009), this withdrawal of short term funding was much like the bank runs observed in the late 19th and early 20th centuries. The main difference is that the withdrawals were not conducted by customers queuing at bank branches to withdraw cash but rather by wholesale customers failing to renew maturing asset backed commercial paper loans to conduits and SIVs or by demanding much higher levels of collateral in repo markets. These were wholesale runs not, because of deposit insurance and government guarantees, retail deposit runs.

The accepted policy response when facing such a withdrawal of uninsured bank deposits is for the central bank to provide collateralised loans to banks i.e. for the central bank to act as 'lender of last resort'. Central banks have responded in this way to the crisis, especially in September and October of 2008. [Add a table of the Federal Reserve balance sheet illustrating the large scale expansion]. Even before this height of the crisis over the previous 15 months, central banks were providing substantial amounts of collateralised 'term loans' in an attempt to reduce the gaps between unsecured money market and good collateral lending rates.

Figure 9.1 illustrates. From August of 2007 onwards, the illiquidity in structured credit markets resulted in an unusually large spread emerging between unsecured Libor borrowing rates and the rate of borrowing on good collateral such as UK or US government bonds.

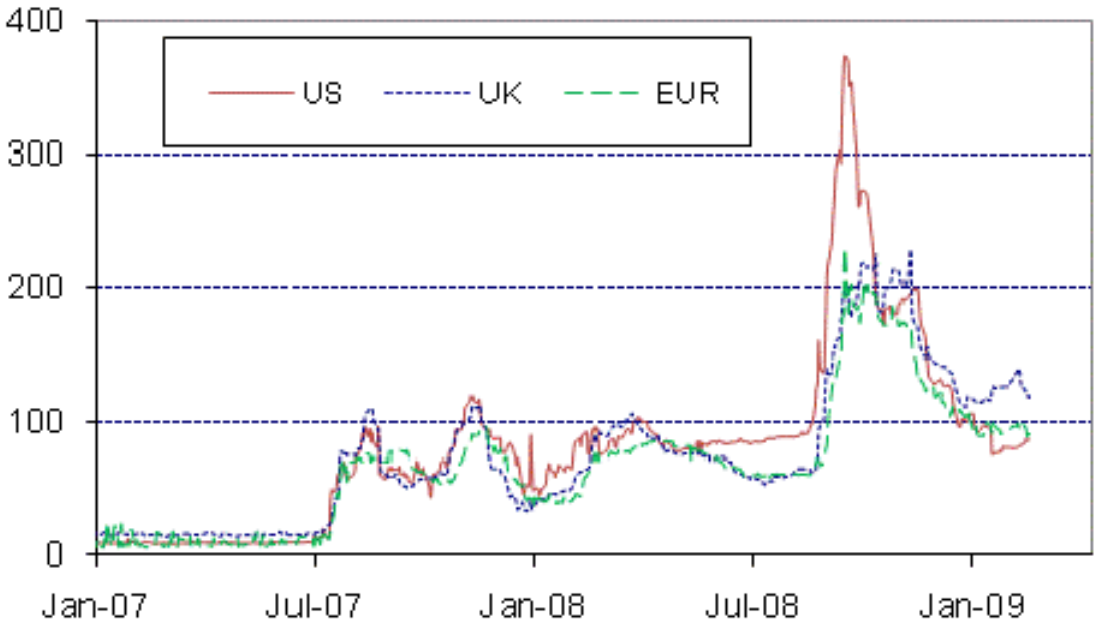


Figure 9.1. Libor vs. good collateral repo rates (three-month) *Source:* Bloomberg

An issue this raises is why the provision of central bank lending did not quickly bring these spreads back to previous low levels?

The most obvious answer is that central bank ability to lend is limited in much the same way as interbank lending, by the availability and market pricing of collateral.

Discussion of central bank collateral rules and the extension of these rules by the Federal Reserve and the Bank of England. The very broad extension of autumn of 2008.

Discussion of the central bank asset swaps

Why then did this robust response not bring the illiquidity of Central banks have done what lending they can within the limits set by their own limits on credit exposure. Greater support of short term money markets would require either that central banks to accept much greater exposure to credit risk than they have in the past or that central government accept this risk. There is a case for such a response but it would mark a sharp departure from previous policy.

Mehrling and Milne (2008) and Gorton (2009) have argued that government authorities could directly address this illiquidity of collateral by providing public sector guarantees of AAA senior structured credit tranches. There are however major political obstacles to such a policy.

Discussion of ‘moral hazard’

Discussion of the new liquidity polices.

5. Summary and conclusions

This paper has argued that the recent stresses in credit and money markets are explained by the widespread ‘maturity mismatch’ in the holdings of senior structured credit securities. These securities are of very low default risk but they were mostly held by banks and financed using short term repo and ABCP funding. This then triggered a feedback loop that undermined the pricing and liquidity of these securities.

Central banks have responded to these problems and the resulting liquidity pressures on commercial banks by offering collateralised lending and preventing widespread bank collapse.

However the ability of the central bank to act as a lender of last resort in this way is limited by its willingness to accept credit risk. The central bank has only willing to accept collateral on broadly similar terms as private sector lenders, and relies on private sector pricing in order to guage its own credit risk. Central banks have been unable to become the market makers for these illiquid securities because doing so would expose them to substantial mark to market risks which they are unable, under current institutional arrangements, to bear.

The central bank may accept collateral which is shunned by the private sector. In this case it can offset the withdrawal of deposits in a bank run. But such lending, even if collateralised lending, still poses a credit risk to the public sector as a whole. If a bank eventually fails and the claims of debt holders and the deposit insurance fund written down to the value of bank assets, then, to the extent that its loan portfolio has been pledged against lending by the central bank, the greater is the exposure of the deposit insurance fund.

Central banks have responded by lending to banks facing difficulties in fundin themselves in interbank markets. This is the modern ‘lender of last resort’ in which commercial banks, and possibly also other market participants, are able to discount securities with the central bank, using them as the collateral for repo lending from the central bank instead of from the market. Alternatively, as both the Federal Reserve and the Bank of England have done during the recent crisis, central banks may also offer swaps of liquid Treasury securities acceptable in the market for repo borrowing for illiquid senior AAA structured credit securities. However the pricing and terms of these facilitie are limited by concerns that such discounting or asset swaps may expose the central bank to unacceptably large credit risk.

This then raises major policy questions about the future support of structured credit markets. There is a case for permanent government backed insurance of the default risk free but illiquid securities, through a scheme of default insurance. But this has to be a responsibility of central government not of the central bank.

The proposed measures to prevent such illiquidity problems recurring, introducing rules that will force banks to hold liquid securities such as government bonds, are misconceived. They do not deal with the underlying problem of excessive reliance on wholesale funding and on the unwillingness of long term investors to hold collateralised bank issued securities.

Appendix

This Appendix seeks to develop a formal model of the 'illiquidity spiral' illustrated in Figure 1.1 above.

There are two existing strands of literature, modelling illiquidity. The first are models of exogenous liquidity risk in markets for bank and corporate borrowing (beginning with Bryant (1980) and Diamond and Dybvig (1983). A valuable recent statement and review is found in Holmstrom and Tirole (2009), Wicksell lectures.

The second are models of endogenous liquidity risk in security markets, notably the work of Shin, Danielsson and co-authors.

The model of this appendix seeks to combine these two strands of literature, introduce endogenous illiquidity in the market for collateral as an explanation of bank deposit withdrawals and funding.

3.1 The case of complete markets. This is a preliminary to introduction of banks and mutual funds in section 3.2.

There are N firms indexed by n. There is a single period of economic activity. During this period firm n uses labour to produce output according to $y_n = \theta f(l_n) + \varepsilon_n$ where l_n is labour employed, θ is an aggregate productivity shock with an expected value of unity, and ε_n is a firm specific and fully diversifiable (because $\sum_n \varepsilon_n = 0$) shock. All N firms employ the same amount of labour (later this assumption will be relaxed) and therefore aggregate labour demand is $L = \sum_n l_n$ and aggregate output is $Y = \theta N f(l_n) = \theta F(L)$.

There is a single representative household and a competitive labour market. This household supplies labour during the period and then consumes at the end of the period. This household supplies labour to maximise the following expected utility function, separable in leisure and consumption:

$$u = g(N - L) \int v(C(\theta)) z(\theta) d\theta$$

where N is the endowment of aggregate labour and L is labour supplied (so that $N - L$ is the consumption of leisure), $C(\theta)$ is consumption in state θ and $z(\theta)$ is the probability density for θ.

The assumption of separability allows us to analyse separately the leisure-consumption decision and valuation of consumption in different states of the world.

Denote by Q a consumption plan in which the household consumes an amount $C(\theta) = \theta Q$ in state θ and let $h(Q) = \int v(\theta Q)z(\theta)d\theta$ so that utility can then be written as:

$$u = g(N - L)h(Q)$$

There are two cases of interest. The first is when the aggregate productivity shock arrives at the end of the period, after the determination of wages and employment but before output is produced (this could for example be an agricultural economy and the productivity shock is the harvest yield). The second is when the aggregate productivity shock is revealed at the beginning of the period before the determination of wages and employment. It is useful to explore both of these cases. One reason is that we will eventually want work with a model in which uncertainty is revealed in two stages, with a partially revealing 'signal' followed by later full revelation and these are the two polar cases.

In both cases is then only one relative price in this economy, the real wage, denoted by w. We can solve for general equilibrium as follows. First solve for profit maximising output and labour demand of each firm, given the real wage. Then use the first order condition for maximisation of household utility to establish the supply of labour for any given level of consumption. The general equilibrium corresponds to the value of the real wage at which aggregate output equals aggregate consumption and labour supply equals labour demand.

To analyse the case where employment and output is decided before the aggregate productivity shock, choose as a numeraire the composite consumption good providing θ of consumption in state θ. Wage contracts pay a wage rate of w units of the consumption good. In terms of this numeraire firm profits are then given by $\pi_n = f(l_n) - wl_n + \varepsilon_n$. The first order condition for profit maximisation is $f'(l_n) - w = 0$, yielding firm specific labour demand $l_n = f'^{-1}(w)$ and aggregate labour demand:

$$L^d = Nf'^{-1}(w) \tag{1}$$

while aggregate output in state θ is given by:

$$Y(\theta) = \theta F(L^d) = \theta N f\left(f'^{-1}(w)\right) \tag{2}$$

The first order condition for household utility maximisation is $wg'(N - l^s) = h'(Q) = \int v'(\theta Q)\theta z(\theta)d\theta$. Using the labour market and goods market clearing conditions $L^s = L^d$ and $Q = F(L^d)$ this becomes:

$$wg'\left(N\left(1 - f'^{-1}(w)\right)\right) = \int v'\left(\theta N f\left(f'^{-1}(w)\right)\right)\theta z(\theta)d\theta \tag{3}$$

and (3) can be solved for the equilibrium real wage w^*, hence yielding aggregate employment and output. Note that $v'\left(\theta N f\left(f'^{-1}(w)\right)\right)z(\theta)$ is the risk-neutral transformation of the natural probability density $z(\theta)$. This first order condition states that the marginal return to labour (the left hand side of (3)) equals the risk-neutral expected marginal utility of consumption (the right hand side of (3)). This risk-neutral probability density can also be used for the valuation of securities including firm equity.

The case where employment and output are decided after the productivity shock is solved in similar fashion, with the difference that now the demand for labour is state dependent and the equilibrium wage rate depends on actual rather than expected marginal utility. $L^s = L^d = Nf'^{-1}(w/\theta)$ and aggregate output is $Y(\theta) - \theta F(L^s) - \theta N f\left(f'^{-1}(w/\theta)\right)$ and there is a state dependent equilibrium wage rate, determined by the first order condition:

$$wg'\left(N\left(1 - f'^{-1}(w/\theta)\right)\right) = v'\left(\theta N f\left(f'^{-1}(w/\theta)\right)\right) \quad (4)$$

3.2 Introducing financial intermediation.

This section introduces both banks and mutual funds into the model. The role of banks is to overcome a monitoring problem. Households supply labour but if they contract directly with employers they cannot ensure that they are actually paid (the firm specific productivity shock ε_n is not observable by employees, but banks have a monitoring technology that allows them to prevent false claims of poor output). Transactions instead take place as follows. At the beginning of the production period banks make loans to firms, who in turn use this money to pay wages. These wages are paid by crediting bank deposit accounts held by the representative household.

The mutual funds hold the equity of firms. The representative household also holds the shares in these mutual funds. At the end of the period firms sell their output on the goods market for bank money, crediting any profit to the bank deposits of the representative household via the mutual funds and the representative household then uses these bank deposits to purchase the consumption good.

We can re-express the profit of firms, in terms of unit of account of bank money, as $\pi_n(\theta) = P(\theta)\theta f(l_n) - W l_n$ where P is the nominal price level for units of output in state θ and W is the nominal wage rate. Real bank lending is still determined as in Section 3.1, yielding $w^* = W / \int P(\theta)\theta d\theta$ from equation (3).

What then determines the nominal price level $\int P(\theta)\theta d\theta$ and the nominal wage W? This is determined by the need for banks to maintain a means of payment between themselves, and the supply of this means of payment by the central bank. Let the nominal reserves provided to the banking system be R. Without modelling explicitly we will assume that there is an inventory cost of being short of reserves that declines with decreases in the reserve to deposits ratio $q\left(R/(WL+R)\right)$. The central bank also pays a nominal interest payment on reserves of r. The net return to holding reserves, which also determines the interbank lending rate, is $r+\delta q\left(R/(WL+R)\right)/\delta R$ and as an increasing volume of reserves is supplied then the nominal interbank interest rate falls towards r.

The supply of reserves then restrains the supply of bank lending WL with

3.3 Modelling bank maturity mismatch

This section is intended to develope the model further, by introducing two categories of bank one a net supplier of funds the other a net borrower, together with the possibility of a withdrawal of funds triggering a ‘fire sale’ of bank loans.

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