Liquidity Regulation, Extended Repo and the Real Economy[*]

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November 7, 2016

Abstract

There is no wide agreement on the rationale for liquidity regulation. In this paper, we consider a range of rationales that have been suggested. We argue that they suffer from the problem that they do not take account of the fact that financial innovation allows them to be innovated around. The use of 'evergreen funding' such as 'extendable repos' illustrates how the liquidity coverage ratio introduced by the Basel III agreement can be innovated around. While satisfying the letter of the regulation, the innovative financing does not affect the probability of instability. Financial regulation needs to anticipate potential innovations that make them ineffective. However, this is hard to do without specifying exactly what is allowed in terms of financing vehicles.

[*] Prepared for the Carnegie-Rochester-NYU Conference on Public Policy on "The Macroeconomics of Liquidity in Capital Markets and the Corporate Sector" on November 11-12, 2016.

1. Introduction

One reason why the 2007–2009 financial crisis was so severe and had a global impact was massive illiquidity in many markets, particularly interbank markets. This combined with an extreme exposure of many financial institutions to liquidity needs meant investors ran on a variety of financial institutions, particularly in wholesale markets. Financial institutions and non-financial firms started to sell assets at fire-sale prices to raise cash. As a result, central banks injected huge amounts of liquidity into financial systems.

Before the crisis, bank regulation relied to a large extent on capital regulation. Liquidity regulation was not widely used. The liquidity problems during the crisis led to calls for liquidity regulation. As a result the Basel III accord introduces global liquidity standards. These comprise a Liquidity Coverage Ratio (LCR) to withstand a stressed funding scenario and a Net Stable Funding Ratio (NSFR) to address liquidity mismatches. The LCR started to be implemented in 2015 with full implementation planned for 2019. The NSFR is proposed to be implemented in 2018.

The LCR is a measure of an institution's ability to withstand a severe liquidity freeze that lasts at least 30 days. Liabilities are categorized in terms of the degree of difficulty in rolling them over. Each category is assigned a percentage representing the portion of that liability that remains a source of funding during the next 30 days or is replaced by funds in the same category. Assets are also sorted into categories with each category being assigned a percentage haircut representing the loss that would be incurred if the asset were to be sold in the middle of a severe financial crisis. The LCR is defined as the ratio of High Quality Liquid Assets (HQLA) to total net cash outflows over the next 30 calendar days. The total net cash outflow equals total expected cash outflows minus the minimum of total expected cash inflows and 75 percent of total expected cash outflows. The idea is that the ratio should exceed 100 percent so the financial institution can survive at least 30 days.

The NSFR is designed to reveal risks that arise from significant maturity mismatches between assets and liabilities. It is the ratio of the available amount of stable funding to the required amount of stable funding over a one-year horizon. Stable funding includes customer deposits, long-term wholesale funding, and equity. The required amount of stable funding is calculated by weighting assets (longer-term assets receive higher weights but assets which mature within one year do not necessarily receive a zero risk-weight). Again, the idea is that the ratio exceeds 100%.

An important issue in the construction of such liquidity regulations is the exact nature of the problem they are trying to solve. In other words, what is the market failure they are designed to correct? Why is the provision of liquidity that the market provides insufficient? Are the market failures such that the numerical values in the regulations are sensible? Allen and Gale (2004) and Allen, Carletti and Gale (2014) provide benchmark models and discuss possible market failures. Section 2 below provides a summary of these theories and surveys the literature proposing justifications for liquidity regulation.

In this paper we argue that even if there was agreement on the reasons for liquidity regulation, one of the main problems with these regulations is that it is fairly easy to innovate around them. In fact, innovations involving 'evergreen funding' such as 'extendable repos' are already being used to circumvent the LCR ratio (see, e.g., Alloway (2011, 2015)). In standard repo agreements investors buy bank assets and the bank contracts to buy them back at a particular date. When that date is within 30 days, they count towards the LCR ratio. However, with evergreen funding using extendable repos that usually doesn't happen. The repos are continually renewed by mutual agreement and the notice period is longer than the 30 days mentioned in the regulations so they do not count as short term liabilities for the bank. There was a large surge in these instruments in 2015, presumably as a result of the introduction of the LCR (Alloway (2015)).

Section 3 develops a simple dynamic model to for investigating liquidity regulations such as the LCR. It allows us to show how evergreen funding with an extended notice period does not prevent bank runs and financial instability. In the model, time is continuous and at each date a flow of investors enters the market. Each investor has one unit to invest and discounts the future. The investor waits for an investment opportunity that arrives according to a Poisson process. In the long run, the inflow and outflow of investors are balanced at each point in time and the population remains constant. There are two assets, a short asset that earns a zero return and a long asset that earns a flow return. Only banks can invest in the long asset. Banks promise depositors an interest rate.

Liquidity regulations such as the LCR require that short term liquid assets are sufficiently large relative to short term liabilities. Extendable repos allow such regulations to be met by reducing short term liabilities so that the required ratio can be met without distorting the choice of short term versus long term assets. We model this by assuming that the effect of the liquidity regulation is that they require that deposits backed by long assets require a notice period of 1. Thus, if an investor unexpectedly receives an investment opportunity at time t, he must wait until $t+1$ to invest. There is a cost to this delay. Given the parameters of the model it is possible to calculate the value of the average deposit and an expression the promised interest rate must satisfy. In particular, the inflow of new deposits and the flow of earnings on the bank's assets must equal the outflow of mature assets, including the promised interest payments.

The main point of the model is to show that notice periods do not diminish the risk of runs. If, at any date the depositors decide to run, they will have to wait one period. But if everyone gives notice at the same time, the bank will not be able raise enough money by liquidating assets and the bank will fail. Costs of default (recovery rates less than one) will ensure that anyone who does not joint the run will be worse off. Note that everyone is in the same situation because all debt has the same "maturity," one period, regardless of when they originally deposited their money. So the expectation of a run one period hence gives everyone an incentive to give notice and withdraw at the same time.

The fact that a bank has a breathing space might appear to lessen the chances of the bank failing, but only if the bank reveals the run and asks the central bank for help. The history of the Great Financial Crisis does not suggest that banks are eager to reveal their difficulties until forced to do so. If, instead, it sought to find alternative funding sources and or arrange a merger, the central bank might not be aware of trouble until it is too late to do anything.

We have used the language of extendable time deposits above, but the structure of many other kinds of extendable debt will lead to the same results. Note that the use of secured debt does not make the bank safer. To the extent that it encumbers assets that might otherwise be available to pay unsecured creditors, it will weaken the claims of the unsecured depositors and make it more likely that they will run (without the delay forced on the repo holders).

It is interesting that as discussed above evergreen funding instruments with the kinds of characteristics modelled above have recently been developed and are being used in increasing quantities (see Alloway (2015)). One of the important implications of the paper is therefore that regulators need to anticipate financial innovations and devise regulations that cannot be innovated around. Otherwise the regulations will not have the intended effect and will not influence the real economy. Our main point is that with liquidity regulation this is particularly difficult to do.

2. Benchmark models of liquidity provision and literature review

Real models of liquidity provision in the financial system

In recent decades, interbank markets have come to play an increasingly significant role in the funding of banks. Ideally, these markets should ensure an efficient liquidity transfer between surplus and needy banks. They are the focus of central banks' implementation of monetary policy and a smooth functioning of interbank markets is essential for maintaining the stability of the overall financial system. Despite this key role and the potentially significant effect their functioning has on the whole economy, there was not a large literature studying interbank markets prior to the crisis.

Bhattacharya and Gale (1987) was the pioneering theoretical study in this area. Their model provides a foundation for the analysis of the functioning of financial markets and financial intermediaries, liquidity provision and financial fragility. However, in the Bhattacharya-Gale setup, the characterisation of interbank markets is quite rudimentary and, in addition, interbank markets are not part of an optimal arrangement. It is important to have a framework with a role for both financial intermediaries and for markets, modelled from first principles. Allen and Gale (2004) develop such an approach. They argue that in modern financial systems financial markets and financial intermediaries are complementary. As in Diamond and Dybvig (1983), intermediaries provide an insurance function to consumers against their individual liquidity shocks. However, individual investors cannot trade directly in the full range of markets since it is too costly for them due to information and transaction costs. This is the reason why markets also play an important role in this environment. Markets allow financial intermediaries (and hence their depositors) to share risk. Intermediaries such as banks and mutual funds can invest in financial markets. They provide risk-sharing services by packaging existing claims on behalf of investors who do not have access to markets and, of course, are trading these claims on markets. Such a general equilibrium framework allows a normative analysis of liquidity provision by the financial system.

Consumers deposit funds into banks which provide liquidity insurance such that depositors can withdraw whenever they have liquidity needs. Banks accumulate the funds and lend them to firms to fund long-term investments. There are two types of uncertainty concerning liquidity needs which makes liquidity management on the part of banks quite difficult. The first is that each bank is exposed to idiosyncratic liquidity risk. At any given date its customers may have more or less liquidity needs. The second type of uncertainty is aggregate liquidity risk which banks have to face. In some periods, liquidity demand is high while in others it is low, thereby exposing all banks to the same shock at the same time.

What Allen and Gale (2004) analyze in such a framework is the ability of banks to hedge themselves against these shocks. They show that this crucially depends on the completeness of financial markets. If markets are complete in the sense that for each aggregate state an Arrow security can be traded, then the financial system provides liquidity efficiently as it ensures that banks' liquidity shocks are hedged. In particular, they show that in an environment with complete markets and in which intermediaries can offer complete contingent contracts, the resulting allocation is incentive-efficient. With complete contracts, the consequences of default will be anticipated and therefore included in the contract, so default and financial crises do not occur. If intermediaries can only offer incomplete contracts -- a case in point is where banks only offer deposit contracts -- default can improve welfare by improving the contingency of contracts. Thus, financial crises do occur in such a model, but are not necessarily a source of market failure. Hence, even in this case with incomplete contracts, the financial system provides optimal liquidity and risk sharing if markets for aggregate risks are complete. A set of complete and perfect financial markets, which includes of course interbank markets, is necessary for efficient functioning of the financial system.

If markets are incomplete, then there may be too much or too little liquidity, and government regulation may be welfare-improving. Allen and Gale (2004) consider an example where there are complete markets for hedging aggregate asset return shocks but no markets for hedging aggregate liquidity shocks. In this case it is shown that liquidity regulation can improve aggregate welfare.

There are many other deviations from the efficient framework in Allen and Gale (2004) that constitute market failures. Interbank markets did not function well during the crisis and this has led to some interesting recent contributions analysing how they malfunctioned. Freixas and Jorge (2008) examine how asymmetric information in the interbank market affects liquidity provision and the monetary policy transmission mechanism. In a similar vein, Heider, Hoerova and Holthausen (2009) analyze the functioning of interbank markets when there is adverse selection. Bolton, Santos and Scheinkman (2011) provide a theory of liquidity provision with asymmetric information in which there is an adverse selection problem due to the superior information that intermediaries have about the assets they hold. Diamond and Rajan (2011) relate the seizing up of term credit to an overhang of illiquid securities because of the possibility of future fire sales. Acharya, Gale and Yorulmazer (2011) show that markets for rollover debt such as asset-backed commercial paper can freeze if information arrives in a particular way. Bolton, Santos and Scheinkman (2011) provide a theory of liquidity provision in which there is an adverse selection problem due to the superior information that intermediaries have about the assets they hold that can cause a market freeze. Acharya, Gromb and Yorulmazer (2012) show how the effects of monopoly power in the interbank market when there is asymmetric information can be offset by the central bank providing liquidity. Although most of these papers are concerned with understanding the failure of markets and their effect on liquidity provision, they do not consider interventions such as liquidity regulations to counter the effects of these failures.

The role of central banks in providing liquidity

At least since the work of Bagehot and the 19th and 20th century interventions by the Bank of England, it has been recognised that central banks have a crucial role to play in the prevention and management of financial crises. In his influential book, *Lombard Street*, Bagehot (1873) laid out his famous principles for how a central bank should provide liquidity to banks during a crisis.

- Lend freely at a high rate of interest relative to the pre-crisis period but only to solvent but illiquid borrowers with good collateral (ie any assets normally accepted by the central bank).
- The assets should be valued at between panic and pre-panic prices.
- Institutions without collateral should be allowed to fail.

Despite being written over 140 years ago, these principles are still widely quoted and used as the foundation for many central bank policies. However, their validity in terms of modern financial economics has only been considered in a few papers.

Rochet and Vives (2004) is one of these that has recently examined the Bagehot principles. In particular, the authors focus on Bagehot's assertion that the lender of last resort (LOLR) should lend to any solvent but illiquid banks. In the past, several authors, such as Goodfriend and King (1988), have dismissed this view as obsolete since in modern interbank markets it cannot be the case that a solvent bank is illiquid. Of course, in light of the recent crisis, one can have serious doubts about the validity of this argument. For this reason, it is even more interesting that Rochet and Vives (2004) provides a theoretical foundation supporting Bagehot's doctrine regarding this dimension. An important problem in the banking literature in the spirit of Diamond and Dybvig (1983) is that the fragility of banks depends crucially on possible coordination failures between depositors that can trigger bank runs. Given the assumption of first-come, first-served, and costly liquidation of long-term assets, there are multiple equilibria, which make it hard to base any policy recommendations on such a framework. Using a global games approach, Rochet and Vives develop a theory which does not rely on multiple equilibria. Instead, their model produces a unique Bayesian equilibrium that is characterised by a positive probability that a solvent bank cannot get enough liquidity assistance in the market. Hence, in this respect the Bagehot doctrine still has a solid theoretical foundation.

One of the criticisms of the kind of LOLR policy advocated by Bagehot is that it creates a moral hazard problem in the sense of increasing the incentives for banks to take more risk. Repullo (2005) investigates this claim about LOLR lending. By modelling the strategic interaction between a bank and a LOLR, he shows that in general this proposition is not true. He assumes a bank which is funded with insured deposits and equity capital is subject to capital requirements and can invest, like in a Diamond-Dybvig framework, in two assets: a safe liquid asset and an illiquid asset, whose risk will be privately chosen by the bank. Since deposits are randomly withdrawn, the bank is subject to liquidity shocks. Because the bank optimally will not invest all its endowment in liquidity, in case of a large negative withdrawal shock it has to rely on emergency lending from a LOLR to avoid being forced into liquidation. In this setting, Repullo shows that in equilibrium the bank chooses a risk level that is decreasing in the capital requirement and increasing in the penalty rate charged by the LOLR. However, in the case where the LOLR does not charge the penalty rate, there is an irrelevance result regarding the risk choice. Irrespective of the existence of a LOLR, the bank chooses the same level of risk, but the liquidity buffer chosen is lower when a LOLR exists.

When there are insufficient opportunities for banks to hedge aggregate and idiosyncratic liquidity shocks, Allen, Carletti and Gale (2009) show that the interbank market is characterised by excessive price volatility. They analyse how the central bank should intervene to restore efficiency. By using open market operations to fix the short-term interest rate, the central bank can prevent price volatility and implement the constrained efficient solution. Thus, the central bank effectively completes the market, a result in line with the argument of Goodfriend and King (1988) that open market operations are sufficient to address pure liquidity risk in the interbank markets. Interestingly, one implication of the model is that situations where banks stop trading with each other can be a feature of the constrained efficient solution implemented by central bank policy if aggregate uncertainty is high. Banks may hoard liquidity because they may need it to meet high aggregate demand. When aggregate demand is low, however, they have enough liquidity to meet idiosyncratic shocks and accordingly do not need the interbank market. As a result, the volume in the market falls to zero, but there is no need for central banks to intervene since the freeze is consistent with constrained efficiency.

Freixas, Martin and Skeie (2011) develop a model with aggregate liquidity risk, which like Allen, Carletti and Gale (2009) also has idiosyncratic liquidity shocks to banks. They suggest that inducing low interbank market rates in states of financial disruptions is an optimal policy response of the central bank. As they argue, a primary role for banks in the presence of incomplete markets is to provide better risk-sharing possibilities and more liquidity than markets. Yet during financial disruption, the banks themselves face considerable uncertainty regarding their own idiosyncratic liquidity needs. Hence, they may have large borrowing needs in the interbank market. They show that an interbank market can achieve the optimal allocation, which implies efficient risk sharing to consumers and effective insurance for banks against idiosyncratic liquidity shocks. In the optimum, however, the interest rate in this market must be state-contingent and low in states of financial disruption. This suggests a role for the central bank, which in their model can implement the efficient allocation by setting the interest rates in the interbank market.

Monetary models of liquidity provision by the central bank

The models discussed so far, like most models in banking, treat banking as a real activity with no role for fiat money. While "real" models have provided valuable insights into the nature of financial fragility, they do not capture important aspects of reality, such as the role of fiat money in the financial system. In practice, financial contracts are almost always written in terms of money. This fact has important consequences for the theory. Because the central bank can costlessly create fiat money in a crisis, there is no reason why the banking system should find itself unable to meet its commitments to depositors. Willem Buiter (2007) has made this point as follows.

> "Liquidity is a public good. It can be managed privately (by hoarding inherently liquid assets), but it would be socially inefficient for private banks and other financial institutions to hold liquid assets on their balance sheets in amounts sufficient to tide them over when markets become disorderly. They are meant to intermediate short maturity liabilities into long maturity assets and (normally) liquid liabilities into illiquid assets. Since central banks can create unquestioned money at the drop of a hat, in any amount and at zero cost, they should be the money providers of last resort both as lender of last resort and as market maker of last resort...."

There are a number of papers that consider the relationship between money and financial stability. Much of this early literature seeks to explain historical crises that occurred at a time when fiat currency played an important role in the financial system. An early contribution is Champ, Smith and Williamson (1996). They address the issue of why Canada had no banking crises in the late 19th and early 20th centuries while the United States had many. Their explanation is that Canada allowed the amount of money in circulation to expand to meet demand during harvest time while this could not happen in the US financial system. The effect of this difference was that in Canada liquidity shocks could be easily absorbed but in the United States they led to banking panics. Since currency played an important role during this period, the authors use an overlapping generations model with two-period lived consumers to justify the use of currency. The consumers live in two different locations. Instead of random preference shocks as in Diamond and Dybvig (1983), consumers are subject to relocation shocks. Each period a random proportion of young consumers in each location is forced to move to the other location. These shocks are symmetric so that the population in each place remains constant. Banks make risk-free loans, hold reserves of currency, issue bank notes, and write deposit contracts that are contingent on the proportion of the consumers that relocate. When young consumers relocate they can transport currency or the notes issued by the banks with them but nothing else. The authors show that if the banks are allowed to vary their issuance of notes to accommodate different levels of relocation shocks then there exists a stationary Pareto-optimal equilibrium. In this equilibrium, currency and banknotes are perfect substitutes and the nominal interest rate is zero. However, if the bank note issuance is fixed such that the random relocation demand cannot be accommodated, there will be a banking crisis if the shock is large enough to exhaust the banks' currency reserves. The authors interpret these two possibilities as being consistent with the Canadian and United States experiences from 1880–1910.

Antinolfi, Huybens and Keister (2001) build on the model of Champ, Smith and Willamson (1996) by replacing the private issue of bank notes with a LOLR that is willing to lend freely at a zero nominal interest rate. A stationary Pareto-optimal equilibrium again exists but in addition there is a continuum of non-optimal inflationary equilibria. Antinolfi, Huybens and Keister are able to show that these can be eliminated if the LOLR places an appropriately chosen upper bound on the amount that each individual bank can borrow or is willing to lend freely at a zero real interest rate.

Smith (2002) considers a similar model with two-period lived overlapping generations, where spatial separation and random relocation introduces a role for money and banks. He shows that the lower the inflation rate and nominal interest rate, the lower is the probability of a banking crisis. Reducing the inflation rate to zero in line with the Friedman rule eliminates banking crises. However, this is inefficient as it leads banks to hold excessive cash reserves at the expense of investment in higher yielding assets.

Diamond and Rajan (2001) develop a model where banks have special skills to ensure that loans are repaid. By issuing real demand deposits, banks can precommit to recoup their loans. This allows long term projects to be funded and depositors to consume when they have liquidity needs. However, this arrangement leads to the possibility of a liquidity shortage in which banks curtail credit when there is a real shock. Diamond and Rajan (2006) introduce money and nominal deposit contracts into this model to investigate whether monetary policy can help alleviate this problem.

They assume there are two sources of value for money. The first arises from the fact that money can be used to pay taxes (the fiscal value). The second is that money facilitates transactions (the transactions demand). They show that the use of money can improve risk sharing since price adjustments introduce a form of state contingency to contracts. However, this is not the only effect. Variations in the transaction value of money can lead to bank failures. Monetary intervention can help to ease this problem. If the central bank buys bonds with money, this changes liquidity conditions in the market and allows banks to fund more long-term projects than would be possible in the absence of intervention.

Allen and Gale (1998) develop a model of banking crises caused by asset return uncertainty with three dates, early and late consumers as in Diamond and Dybvig (1983), and initially, real contracts. Building on the empirical work of Gorton (1988), it is assumed that at the intermediate date investors receive a signal concerning the return on the banks' long-term assets. If the signal indicates returns are sufficiently low, the late consumers will withdraw their deposits along with the early consumers and there will be a banking crisis. Allen and Gale go on to show that if contracts are written in nominal terms and a central bank can supply money to commercial banks, the incentive-efficient allocation can be implemented: the central bank gives money to the banks and they then pay this out to depositors. The early depositors use their money to buy goods from early-withdrawing late consumers who then hold money until the final date. Variations in the price level allow risk sharing.

Skeie (2008) develops a standard banking model with nominal contracts and inside money where depositors are subject to preference shocks in the usual way. There is no aggregate liquidity risk or return uncertainty. In contrast to Diamond and Dybvig (1983), Skeie shows that there is a unique equilibrium and it is efficient. If deposits are withdrawn by late consumers at the intermediate date, the price of the consumption good adjusts and this discourages such withdrawals. In order for there to be runs on banks there must be some other friction, such as problems in the interbank market.

Each of the models discussed so far are fairly specific. Again a benchmark model is needed to understand the effects of incorporating money into the analysis. Allen, Carletti and Gale (2014) provide such a model. It is shown in the context of this model, that if the central bank accommodates the demand of commercial banks for liquidity then there will be an efficient allocation of resources.

In the Allen, Carletti and Gale (2014) model in which fiat money is issued by the central bank. Deposit contracts and loan contracts are denominated in terms of money and money is used in transactions. In other words, money is both a unit of account and a medium of exchange. In contrast to the previous literature, it is shown that the combination of nominal contracts and a central bank policy of accommodating commercial banks' demand for money leads to first best efficiency in a wide range of circumstances. The result holds when there are aggregate liquidity and asset return shocks and also when there are idiosyncratic (bank specific) liquidity shocks.

Time is represented by a sequence of three dates and, at each date there is a single good that can be used for consumption or investment. Assets are represented by constant returns to scale technologies that allow the consumers' initial endowment of the good to be transformed into consumption at the second and third dates. The short-term asset is represented by a storage technology: one unit of the good invested in this technology yields one unit of the good at the next date. The long-term asset is represented by a technology that requires an investment at the initial date and yields a random return at the final date. The expected return of the long-term asset is greater than the return of the short-term asset.

There is a large number of ex ante identical consumers, each of whom is endowed with one unit of the good at the initial date. At the beginning of the second date, each consumer receives a time-preference shock that makes him either an early consumer, who wants to consume only at the second date, or a late consumer, who wants to consume only at the third date. The proportion of early and late consumers is itself random, an important source of aggregate uncertainty.

The first best allocation is characterized as the solution to a planner's problem. The planner invests the consumers' endowments in a portfolio of short- and long-term assets and then distributes the returns to these assets to the early and late consumers. The portfolio is chosen before the realization of the aggregate state, that is, the fraction of early consumers and the return on the risky asset. The consumption allocation is determined after the realization of the aggregate state and is therefore state contingent. It is shown how this allocation can be implemented using a simple institutional structure and non-contingent nominal contracts.

In the decentralized economy, there are three types of institutions -- a central bank, commercial banks and firms. At the initial date, the central bank makes money available to the commercial banks on an intraday basis at a zero interest rate. The banks make loans to the firms and the firms in turn use the money to buy the consumers' endowments and invest them in the short- and long-term assets. At the intermediate and final dates, the central bank again makes intraday loans to the banks. The banks use this money to pay for depositors' withdrawals. The depositors in turn use the money to purchase goods from the firms. Then the firms use the same money to repay their loans to their banks and the banks use it to repay the central bank. The central bank's policy is passive: at each date it supplies the amount of money demanded by the commercial banks. Commercial banks and firms are assumed to be profit maximizing but in a competitive equilibrium they earn zero profit. Consumers are expected utility maximizers, but in equilibrium their decision problem is simple: they deposit the money received in exchange for the sale of their endowments at the first date and withdraw and spend all their money at the second or third date, depending on whether they are early or late consumers.

The main result is to show that a competitive equilibrium implements the same state-contingent allocation as the planner's problem, even though deposit contracts represent a fixed claim (in terms of money) on the banks. In spite of the debt-like nature of the deposit contract, it is possible to implement a state-contingent allocation because deposit contracts are written in terms of money. Regardless of the liquidity and asset return shocks, banks are able to meet their commitments as long as the central bank supplies them with sufficient amounts of fiat money. The price level adjusts in response to aggregate shocks in order to clear markets. When the number of early consumers is high, the amount of money withdrawn from the banks is also high and this increases the price level. When the returns on the long asset are low, the supply of goods is also low and this increases the price level. The adjustments in the price level ensure that early and late consumers receive the efficient, state-contingent levels of consumption.

A central bank policy of passively accommodating the demands of the commercial banks for liquidity is sufficient to eliminate financial crises and achieve the first best. The role of the central bank is simply to provide the necessary money so that each bank can meet withdrawals by its depositors. Price level adjustments lead to the optimal level of real balances and the optimal allocation of consumption at each date.

The baseline model can be extended in a number of ways. Idiosyncratic (bank-specific) liquidity shocks can be introduced without upsetting the efficiency results. The interbank market allows banks to reshuffle money between banks that receive high and low liquidity shocks at the second date so that each bank can meet the required level of withdrawal by its depositors, without being subject to distress. The process is reversed at the third date, so that banks with a large proportion of late consumers can meet the higher number of withdrawals then. First best efficiency can be achieved by monetary policy alone when the model is extended to allow for idiosyncratic (bank-specific) liquidity risk and multiple periods.

Accommodative monetary policy alone is not always sufficient to achieve efficiency, however. In particular, it does not allow the sharing of idiosyncratic (bank-specific) asset return risk. If the banks' asset-specific returns are observable, the government could introduce an insurance scheme. Alternatively, a private scheme could achieve the same end by securitizing the assets and allowing banks to hold a diversified portfolio of asset backed securities. Such schemes are vulnerable to moral hazard if there is asymmetric information about asset returns. Insuring low returns gives banks an incentive to engage in asset substitution and to misrepresent the realized returns of the assets. Clearly, pooling idiosyncratic return risks is more difficult than implementing an accommodative monetary policy.

Both in the case of real models of central bank interventions and monetary injections, benchmark models have been identified and the role of market failures considered. Although liquidity is the key issue in these analyses, liquidity regulation of banks is usually considered only in passing, if at all.

Justifications for liquidity regulation

While there has been a great deal of academic literature on capital regulation there has been little on liquidity regulation, particularly before the crisis. The literature discussed in the previous sections considered various aspects of liquidity provision including the role of the central bank but did not consider liquidity regulation except in passing.

Rochet (2004, 2008) are early contributions. These papers focus on a number of market failures that can justify liquidity regulation. These include potential problems in payment systems, moral hazard problems at the individual bank level due to opaqueness of assets, and moral hazard at the aggregate level due to expectations of a generalized bailout if there are macro shocks. Rochet argues that while simple liquidity ratios can potentially deal with the first two, more complex regulation based on a banks' exposure to macros shocks may be necessary for the third problem.

Perotti and Suarez (2011) develop a formal model of liquidity regulation based on Pigovian taxes. The basic market failure is due to an externality. Even though each individual bank takes into account its own exposure to refinancing risk, it does not internalize the system-wide effect of its decision. This externality results in too much short term funding and the problem is to mitigate this effect. Banks differ in their ability to extend credit and their incentives to take risk. Depending on which of these types of heterogeneity is dominant, the socially efficient allocation can be obtained with some combination of Pigovian taxes and quantity regulations. When banks differ in credit opportunities, Pigovian taxes are best. However, when they differ in their risk taking incentives, net funding ratios are best. If capital controls can be used as well as liquidity ratios, then taxes can again be optimal.

In a related contribution, Stein (2013) develops a framework where the market failure is that banks do not take into account all the social benefits of increased liquidity reserves in terms of enhanced financial stability and lower costs to taxpayers. The central bank acting as LOLR is one way to solve this problem. However, Stein argues that it is socially costly to use LOLR capacity because it is difficult to distinguish between illiquidity and insolvency. As a result, it may be better to have liquidity regulation. In addition, it may, in cases where high quality collateral is in short supply, be optimal to price access to the LOLR as well.

In addition to these papers analysing the optimal form of regulation, Bech and Keister (2013) consider the effect of liquidity regulation on the implementation of monetary policy. Since monetary policy is typically implemented by central banks targeting the rate in the market for central bank reserves, liquidity regulation may change the relationship between market conditions and the interest rate. In Bech and Keister's model, this happens because banks worried about violating the liquidity regulation are more likely to seek term funding in the market. This results in a steeper yield curve at short maturities.

Heider, Hoerova and Calomiris (2015) develop an interesting theory of liquidity regulation based on the substitution possibilities between liquidity and capital. They provide evidence that this substitution occurs empirically. Their theory is based on the idea that it is much easier to verify the value of liquidity on a bank's balance sheet than that of other assets that contribute to its capital position. This allows liquidity regulation to supplement capital regulation in an effective way. Goodfriend (2016) argues that having banks hold reserves at the central bank is a much more effective way of pre-positioning liquid assets on a bank's balance sheet to promote financial resilience than the LCR requirement. The latter in its current form is a very difficult regulation to enforce. Central banks can achieve the same goals much more easily by varying the interest rate on bank reserves held with them.

Diamond and Kashyap (2016) develop a rationale for liquidity regulation based on depositors having incomplete information about the bank's ability to survive a run. The model is an extension of the standard Diamond and Dybvig (1983) framework. The asymmetric information between depositors and the bank leads to a market failure where the bank does not have the correct incentives to hold the right amount of liquidity. It is shown that regulations corresponding to an LCR and NSFR can make runs less likely. However, optimal regulation in this model does not involve these rules.

Bouwman (2014) provides an overview of how banks create liquidity and a survey of the literature on how liquidity should be regulated. She recounts the history of liquidity regulation and points to the paucity of theoretical analysis. In her view, the need for regulation arises because of moral hazard associated with deposit insurance and the discount window. One of the points she stresses is the importance of the interaction between capital and liquidity regulation and the need for both to be done in concert.

The account of the literature on liquidity regulation in this section indicates that it is still at an early stage. In particular, the models the analysis is based on are quite simple and capture only a small part of the market failures that have been identified in the literature on liquidity provision.

At a more basic level, there is no clear analysis of whether liquidity should correspond to short term real assets or to monetary instruments. Real models of banking focus on the former while monetary ones focus on the latter. Distorting the allocation of real assets through regulation may be socially costly. In contrast, if the central bank creates liquidity that is held by commercial banks then that is potentially costless as argued by Buiter (2007).

In what follows, we argue that there is a significant problem with the form of liquidity regulation that has been proposed which the literature discussed does not address at all. This is that financial innovation can be structured to get around the regulations so that they do not have the desired effect. We turn next to a simple example to illustrate this.

3. A simple dynamic model

Time is continuous and, at each date t, there is a flow $f > 0$ of investors into the market. Each investor has an endowment of one unit to invest and discounts the future at the rate ρ. The investor waits for an investment opportunity that arrives according to a Poisson process with parameter λ. In the meantime, he invests his money in a bank.

There are two assets, a short-term asset that earns a zero return and a long asset that earns a flow return of $r > 0$. Only banks can invest in the long asset, but investors have access to the safe asset. The banking market is competitive so banks compete with each other to attract deposits and offer the highest sustainable interest rate on deposits.

At $t = 0$, there are no investors in the market and the deposits in the representative bank are $D = 0$. We assume that the representative bank invests only in the long asset. There is no reason to hold the short asset and the bank can only offer the best returns and attract deposits by investing entirely in the long asset.

At any point in time, the representative bank earns rD from the long asset, receives an inflow of f units of deposits, and an outflow of λD deposits. The rate of change of deposits is

$$\dot{D} = (r - \lambda)D + f. \tag{1}$$

To ensure stability, we assume $r < \lambda$. This equation can be solved for

$$D(t) = \frac{f}{\lambda - \mathrm{r}} - e^{(\lambda-\mathrm{r})(\mathrm{C}-\mathrm{t})},$$

where C is an undetermined coefficient. Because the market opens at $t = 0$ and $D(0) = 0$, we have

$$0 = \frac{f}{\lambda - \mathrm{r}} - e^{(\lambda-\mathrm{r})\mathrm{C}},$$

so the solution of the ODE can be written as

$$D(t) = \frac{f}{\lambda - \mathrm{r}} - \frac{f}{\lambda - \mathrm{r}} e^{-(\lambda-\mathrm{r})\mathrm{t}}. \tag{2}$$

It is clear from equation (2) that

$$\lim_{t\to\infty} D(t) = \frac{f}{\lambda - \mathrm{r}}$$

and from equation (1) that $\dot{D} = 0$ in the steady state when $D = \frac{f}{\lambda - \mathrm{r}}$.

Let *N* denote the number of investors in the market. Then the rate of change of *N* is given by

$$\dot{N} = f - \lambda N,$$

which can be solved for

$$N(t) = \frac{f}{\lambda} - e^{\mathrm{C}\lambda(1-\mathrm{t})},$$

where *C* is another undetermined constant. Since N(0) = 0,

$$0 = \frac{f}{\lambda} - e^{\mathrm{C}\lambda},$$

and

$$N(t) = \frac{f}{\lambda}(1 - e^{1-\mathrm{t}}).$$

Clearly,

$$\lim_{t\to\infty} N(t) = \frac{f}{\lambda}$$

and $\dot{N} = 0$ in the steady state when $N = \frac{f}{\lambda}$. The average deposit *d* = *D/N* is given by

$$\frac{D}{N} = \frac{\frac{f}{\lambda - \mathrm{r}}(1 - e^{-(\lambda-\mathrm{r})\mathrm{t}})}{\frac{f}{\lambda}(1 - e^{1-\mathrm{t}})}$$

$$\frac{D}{N} = \frac{\lambda}{\lambda - r}\frac{(1 - e^{-(\lambda-\mathrm{r})\mathrm{t}})}{(1 - e^{1-\mathrm{t}})}$$

The rate of change of the average deposit is

$$\frac{d}{dt}\left(\frac{D}{N}\right) = \frac{\dot{D}}{N} - \frac{D}{N^2}\dot{N}$$

$$= \frac{(r-\lambda)D + f}{N} - \frac{D}{N^2}(f - \lambda N)$$

$$= \frac{D}{N}\left(\frac{(r-\lambda)D + fN}{D} - \frac{f - \lambda N}{N}\right)$$

$$= \frac{(r-\lambda)DN + fN - fD + \lambda DN}{N^2}$$

$$= \frac{rDN + f(N-D)}{N^2}$$

$$= rd + \frac{f}{N}(1-d).$$

The first term represents the interest paid on the average deposit. The second represents the adjustment for the inflow of new investors with one unit to deposit. There is no similar adjustment for the departure of the investors who received an investment opportunity, because they constitute a representative sample that holds the average portfolio *d*.

Finally, note that the outflow of cash, λD, is less than the sum of the inflow of new deposits plus the asset returns, $rD + f$ as long as the total value of deposits are growing, that is, $\dot{D}$ as defined by equation (1) is positive. But this must be true as long as *D* is less than the steady state amount. It is straightforward to show that, starting from the initial condition $D(0) = 0$, the value of deposits rises monotonically and asymptotically converges to the steady state without ever exceeding $f/(\lambda - r)$. If the model started from an initial condition $D > f/(\lambda - r)$, it would not be viable. The bank would have to pay a negative interest rate to meet the cost of outflows, but that would cause everyone to withdraw and use the short asset instead. In what follows we will focus on the steady state.

4. Bank runs

So far there are no bank runs in the model. There are many ways to introduce these. Perhaps the simplest way is to adapt the model so that there are coordination failures similarly to Diamond and Dybvig (1983). It is assumed that recovery rates when assets are liquidated are less than one. In other words, there are costs of default. This leads to multiple equilibria in the standard way. We assume that the coordination device is a sunspot that occurs with zero probability. The good equilibrium is the same as the one described in the previous section. People deposit their wealth in the bank and withdraw when their investment opportunity arises. The bank uses the inflows from depositors and the return flow from the long term asset to finance the withdrawals. The law of large numbers ensures that the incoming and outgoing payment streams match so there are no bank runs. However, when the sunspot is observed people anticipate a run and it becomes individually rational for depositors to withdraw.

Now suppose that liquidity regulations are introduced such that deposits backed by long assets require a notice period $\Delta = 1$. Thus, if an investor unexpectedly receives an investment opportunity at time t, he must wait until $t + 1$ to invest. The cost of this delay is $\delta = e^{-\rho}$. Let τ denote the Markov stopping time at which the investment option arrives plus the one period delay. Suppose that investors could use the storage technology in lieu of interest-bearing deposits. They would earn no interest, but their wealth would be available immediately.
If an investment option arrived at date t, they could invest their one unit immediately and receive a return R. Alternatively, if the investors used the services of a bank, they would have a larger amount to invest, $E[r\tau]$ in expected value, but the investment would be delayed by a period of unit length. So the investor would prefer to use the bank if and only if $\delta E[r\tau]R \geq R$ or

$$\delta E[r\tau] \geq 1.$$

The longer the expected arrival time of the investment opportunity or the lower the discount rate, the more likely the investor is to prefer banking.

The main point of the model is to show that notice periods do not diminish the risk of runs. If, at any date *t*, the depositors decide to run, they will have to wait one period. But if everyone gives notice at the same time, the bank will not be able to raise enough money by liquidating assets and the bank will fail. Costs of default (recovery rates less than zero) will ensure that anyone who does not joint the run will be worse off. Note that everyone is in the same situation because all debt has the same "maturity," one period, regardless of when they originally deposited their money. So the expectation of a run one period hence gives everyone an incentive to give notice and withdraw at the same time.

The fact that a bank has a breathing space might appear to lessen the chances of the bank failing, but only if the bank reveals the run and asks the central bank for help. The history of the Great Financial Crisis does not suggest that banks are eager to reveal their difficulties until forced to do so. If, instead, it sought to find alternative funding sources and or arrange a merger, central bank might not be aware of trouble until it is too late to do anything.
We have used the language of time deposits, but the structure of extendable or evergreen repos is essentially the same, except for the fact that they are secured debt. The use of secured debt doesn't make the bank safer. To the extent that it encumbers assets that might otherwise be available to pay unsecured creditors, it will weaken the claims of the unsecured depositors and make it more likely that they will run (without the delay forced on the repo holders).

The key point is that liquidity regulation such as an LCR does not prevent bank runs. The financial innovation of extendable repos means that the liquidity regulation does not help. If the

LCR ratio was defined using a longer notice period than 30 days, clearly nothing would change overall in that runs would still occur. In general regulations can be innovated around and this is particularly true for the case of liquidity regulation. We have presented a simple example to demonstrate this but clearly in the standard models of bank runs, a similar result will hold. The letter of the regulation is satisfied but it has no effect. If there is an attempt to rule out particular securities then they can be altered to satisfy the new rules without having any effect on the real economy.

One type of liquidity regulation that would be effective would be to specify a list of securities that can be used and rule out all other possibilities. While this might be desirable in the short term, it would eliminate all types of financial innovation and this would potentially have significant long term costs.

5. Concluding remarks

The main result of this paper is that liquidity regulation in particular and financial regulation in particular needs to be constructed taking into account the fact that there are incentives to innovate around it. Such innovations are difficult to forestall short of specifying exactly what kinds of financing instruments firms can use. However, this type of regulation will rule out beneficial innovations as well and may be quite costly in the long run.

There is no bank capital in the simple model presented, but we could introduce bank capital by assuming that some part of the assets represented capital paid in by shareholders. These shareholders would presumably require a return r which they could otherwise earn themselves. This part of the bank's assets would not be available to cover interest on deposits but would provide a buffer in the event of bank failure. This extension remains a topic for future research.

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