The Dark Side of Bank Wholesale Funding

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Abstract

Commercial banks increasingly use short-term wholesale funds to supplement traditional retail deposits. Existing literature mainly points to the "bright side" of wholesale funding: sophisticated financiers can monitor banks, disciplining bad ones but refinancing solvent ones. This paper models a "dark side" of wholesale funding. In an environment with a costless but imperfect signal on bank project quality (e.g., credit ratings, performance of peers), short-term wholesale financiers have lower incentives to conduct costly information acquisition, and instead may withdraw based on negative but noisy public signals, triggering inefficient liquidations. We show that the "dark side" of wholesale funding dominates the "bright side" when bank assets are more arm's length and tradable (leading to more relevant public signals and lower liquidation costs): precisely the attributes of a banking sector with securitizations and risk transfers. The results shed light on the recent financial turmoil, explaining why some wholesale financiers did not provide market discipline ex-ante and exacerbated liquidity risks ex-post.

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1 Introduction

Commercial banks increasingly borrow short-term wholesale funds to supplement core retail deposits (Feldman and Schmidt, 2001). The funding shortage is caused by intense competition for household savings from mutual funds, life insurance products, etc., and by the rapid growth in lending opportunities. In response, banks tap into wholesale markets to attract liquidity surpluses of nonfinancial corporations, households (via money market mutual funds), other financial institutions, state and local authorities, and foreign entities. Such wholesale funds are usually raised on a short-term rollover basis with instruments such as large-denomination certificates of deposits, brokered deposits, repurchase agreements, fed funds, and commercial paper.

How would this change in funding structure affect bank risks? The existing literature mainly points to the "bright side" of wholesale funding: exploiting valuable investment opportunities without being constrained by the local deposit supply; the ability of wholesale financiers to provide market discipline (Calomiris, 1999) and to refinance unexpected retail withdrawals (Goodfriend and King, 1998).

However, the credit market turmoil that started in 2007 revealed a "dark side" of wholesale funding (Huang and Ratnovski, 2009). Banks can use wholesale funds to aggressively expand lending and compromise credit quality, particularly when financiers exercise insufficient market discipline. Later, at the refinancing stage, there is a risk that wholesale financiers abruptly withdraw upon a hint of negative news (Acharya, Gale, Yorulmazer, 2008), triggering inefficient liquidations.

This paper attempts to reconcile the traditional view on the virtues of wholesale funding with the recent experience. We suggest that wholesale funding is beneficial when informed, but exacerbates inefficiencies and can create severe liquidity risks when uninformed. We then ask:

- What are the incentives for short-term wholesale financiers to invest in the acquisition of information on bank project quality?

- What are the incentives for wholesale financiers to roll over funding or to force a bank into liquidation at the refinancing stage, particularly if they are uninformed?
- What is the optimal seniority for short-term debt vis-a-vis long-term funds, such as retail deposits?
- What are the private incentives for banks to use short-term wholesale funds, and could they diverge from the socially optimal ones? How can the regulator restore the right incentives?

We consider a bank that finances a risky long-term project with two sources of funds: retail deposits and wholesale funds. Retail deposits are sluggish, insensitive to risks (partly because they are insured), and provide a stable source of long-term funding.[1] Wholesale funds are relatively sophisticated as their providers have the capacity to acquire information on bank project quality. However, they are short-term: supplied on a rollover basis and have to be refinanced before final returns realize or the bank will be forced into liquidation.

Our modelling approach builds on Calomiris and Kahn (1991, hereafter CK). We take CK as a benchmark of the "bright side" of wholesale funding. CK show that "sophisticated" wholesale financiers add value through their capacity to monitor banks and impose market discipline (force liquidations) on loss-making ones. Moreover, they show that monitoring incentives of wholesale financiers are maximized when they are senior at refinancing stage, because it allows them to internalize the benefits of monitoring (payoffs in early liquidations).

In practice, short-term wholesale funds indeed enjoy de facto (effective) seniority

[1] The "sluggishness" of retail deposits is a well-established stylized fact (Feldman and Schmidt, 2001; Song and Thakor, 2007). Retail deposits are typically insured by the government. Their withdrawals are motivated mostly by individual depositors' liquidity needs and thus are predictable based on the law of large numbers. Another reason for "sluggishness" are the high switching costs associated with the transaction services that retail depositors received from the banks (Sharpe, 1997; Kim, Kliger, and Vale, 2003). Although some accounts are formally demandable, retail deposits therefore provide a relatively stable source of long-term funds for banks. However, the local retail deposit base is considered quasi-fixed in size, as it is prohibitively expensive to expand in the medium term (Flannery 1982; Billett and Garfinkel, 2004). When the deposit supply is not sufficient to fund all available investment opportunities, banks can choose to attract, in addition, wholesale funds from sophisticated institutional investors.

because of the sequential service constraint and the relative sluggishness of insured retail depositors. This was the main reason why in almost all recent bank failures (e.g., Continental Illinois, Northern Rock, IndyMac) short-term wholesale financiers were able to exit ahead of retail depositors without incurring significant losses. Interestingly, the well-publicized retail run on Northern Rock took place only after the bank had nearly exhausted its liquid assets to pay off the exit of short-term wholesale funds (Shin, 2008; Yorulmazer, 2008).[2]

We then introduce into the benchmark CK model a single novel feature: *a costless but noisy* public signal on bank project quality. This represents public information that wholesale financiers can costlessly process and that is a noisy proxy for bank-specific fundamentals. Examples include market prices or credit ratings for traded assets (e.g., mortgage-backed securities), performance of other similar banks, various market- or sector-wide indicators (e.g., house or energy prices), or bank stock prices. Wholesale financiers may use the public signal when costly private monitoring did not produce precise information on bank fundamentals (because of either low investment in monitoring or merely bad luck).

We show that this minor and plausible change to the CK setup can, under some conditions, lead to outcomes consistent with the "dark side" of wholesale funding seen in recent events. In our model, the presence of a costless but noisy signal:

- Lowers the incentives of wholesale financiers to monitor;
- Gives wholesale financiers excess incentives to liquidate banks based on noisy public information; and
- Importantly, these distortions become stronger when wholesale financiers are *more senior* claimants to the liquidated assets (in contrast to CK).

[2] Marino and Bennett (1999) analyze six major bank failures in the US between 1984 and 1992 and find that uninsured large deposits fell significantly relative to small insured deposits prior to failures. During the New England banking crisis, failing banks experienced a 70 percent decline in uninsured deposits in their final two years of operation while being able to raise insured deposits to replace the outflow. Billett, Garfinkel, and O'Neal (1998) also find that banks typically raised their use of insured deposits vis-a-vis wholesale deposits after being downgraded by Moody's.

The mechanism of these effects is that, absent a noisy public signal, uninformed wholesale financiers always roll over funding at the refinancing stage as banks are on average solvent (no news is good news). However, with a noisy public signal, wholesale financiers (endogenously) uninformed about bank-specific fundamentals can now choose to liquidate a bank based solely on a negative but possibly very imprecise public signal.

The key inefficiency is that the incentives of wholesale financiers to liquidate based on noisy information can be too high compared to the socially optimal ones, particularly when they are senior claimants on the liquidation value. The reason is that senior wholesale financiers can obtain a larger share of the liquidation value of assets, at the expense of providers of long-term funds such as passive core depositors. As a second-round effect, when wholesale financiers anticipate a high likelihood of an early liquidation with a safe exit, they become less interested in acquiring costly private information on bank project quality in the first place.

Therefore, in the presence of a noisy public signal, higher effective seniority of short-term wholesale funds has two effects. One, in line with CK, is the positive first-order effect that rewards monitoring and market discipline efforts. Another, a novel one, is the negative effect that increases the payoff to liquidating banks based on overly noisy information. The socially optimal seniority of short-term wholesale funds must therefore trade off the two offsetting effects. We find that such welfare-maximizing seniority has an interior optimum. While the monitoring incentives of wholesale financiers increase in seniority for low values of seniority (the CK effect), they decrease for higher values of seniority when higher seniority translates purely into more liquidations. Deviations from that interior optimum to either side result in less monitoring and possibly more inefficient liquidations. This result contrasts with the CK benchmark in which higher seniority for the sophisticated funds is always better.

The precision of the noisy public signal (i.e., the probability that it is correct) is one of the key parameters of the model. Its one interpretation is the availability of relevant public signals on individual bank performance. This may vary across banks depending, for example, on asset type. For example, while the market prices of mortgage-backed securities (MBS) or house price changes can shed light on the fundamentals of a typical mortgage bank, few similarly relevant public signals exist for traditional banks that hold mainly relationship-based small business loans. The signal precision can also be interpreted as the correlation between an individual bank's fundamentals with system-wide outcomes or indicators. With the proliferation of "risk transfer" and "risk dispersion" mechanisms, individual bank performances have become increasingly correlated, so that public signals now provide more relevant information on an individual bank's performance. Note, however, that these costless public signals can only provide *imperfect* information on an individual bank's true asset quality.

Our results reveal that the incentives for short-term wholesale financiers to liquidate strategically based on a noisy negative signal are higher, and therefore the welfare-maximizing seniority of wholesale funds (which compensates for excess liquidation incentives) is lower, when:

- *The noisy public signal is more precise*, yet not as precise as to make liquidation decisions based on it socially optimal; that is, an intermediate level of precision.
- *The share of passive funding such as retail deposit is higher.* The seemingly safe buffer of passive retail deposits in fact makes early liquidations less costly for wholesale financiers and discourages them from information acquisition efforts;
- *Liquidation value of bank assets is higher.* Liquidation value reflects bank's cash reserves and the marketability of its long-term assets. By conventional wisdom, a larger liquidity buffer should better protect a bank against withdrawals. However, our setup highlights an offsetting incentive effect: a larger buffer lowers the liquidation costs incurred on the short-term funds when they withdraw.

In a bank cross-section, these predictions suggest that the use of senior short-term funds is beneficial in "traditional" banks that hold mainly opaque and nontradable relationship loans, consistent with the "bright side" predictions of CK. Yet the "dark side" negative effects are likely to play a significant role in banks with large exposures to standardized and tradable arm's length assets with readily available public information.[3] At the same time, we show that private incentives would in fact drive arm's length banks towards actively using senior short-term wholesale funds, since interest rates demanded on them are lowest when assets are marketable and public signals are informative. Therefore, CK's insights best apply to the traditional relationship banking business with limited public information on asset quality, while our model sheds light on the new banking business characterized by arm's length transactions, high interbank correlations, and the availability of relevant public signals such as market prices and credit ratings.

To sum up, we show that the use and high seniority of wholesale funds is not always socially beneficial. There is a trade-off. In the presence of a costless but noisy signal on bank quality, higher seniority can reduce monitoring and encourage inefficient liquidations. Social welfare is constrained-maximized for an intermediate level of seniority, which depends on the bank's funding structure (i.e., share of passive retail deposits on the liability side), the precision of public signals on bank project quality (which often depends on the type of assets held), liquidation value of bank assets, and interest rates offered to wholesale financiers. This is a novel result that usefully contrasts with CK and bears close resemblance to recent developments in the credit market, as well as some earlier instances of bank failures. It reveals the "dark" side of short-term wholesale funding.

The rest of the paper is structured as follows. Section 2 sets up the benchmark CK-type model of "bright side" of wholesale bank funding. Section 3 introduces the costless but noisy signal on bank project quality and analyses the "dark side" of wholesale bank funding. Section 4 discusses the model's limitations. Section 5 concludes.

[3] Note that banks holding securitized assets (e.g. MBS) appear particularly vulnerable to the risk of premature liquidations: trading of assets provides a public signal on quality, and also raises their liquidated value.

2 The Bright Side of Wholesale Funding

We start by outlining a version of the Calomiris and Kahn (1991) model. We use it to describe a benchmark "bright side" of bank wholesale funding. (We will then extend the model to show a "dark side" of wholesale funding.)

We demonstrate a number of effects. First, the use of wholesale funds allows banks to expand the volume of lending beyond constraints of the fixed depositor base. Second, wholesale financiers have the capacity to monitor banks and, if informed, exert welfare-enhancing market discipline: roll over funding to good banks but force liquidation of bad ones. Third, the monitoring incentives of wholesale financiers are maximized when they are senior creditors in early liquidations: this allows them to internalize the benefits of monitoring. Finally, and importantly, profit-maximizing private choices of banks and wholesale financiers are consistent with constrained-optimal outcomes: banks choose a maximum possible amount of wholesale funds and make them senior, to which wholesale financiers respond by monitoring and providing market discipline.

2.1 Model

Consider an economy with three dates: $0, 1, 2$. The economy consists of a bank (with access to an investment project) and two types of bank financiers: retail and wholesale. Everyone is risk-neutral and there is no discounting.

The project A bank has exclusive access to a profitable but risky long-term project. For each unit invested at date 0, the project returns at date 2: X with probability p or 0 with probability $1 - p$. The project has a positive net present value: $Xp > 1$. The project may also be liquidated at date 1 returning $L < 1$ per unit initially invested. The maximum investment size is 1.

Funding The bank has no initial capital and needs to borrow in order to invest. There are two types of financiers:

1. "*Retail depositors*" are unsophisticated and passive. They never get advance information on date 2 project realization, and never withdraw before date 2, providing a bank with a source of stable long-term funds despite being formally demandable. The passiveness of retail depositors is well-supported in the empirical literature; also see Shin (2008) who documents that retail deposits were the most stable source of funding for Northern Rock during the crisis. The interest rate payable on retail deposits (date 0 to date 2) is not risk-sensitive and is fixed at R_D: $1 \leq R_D < pX$ (risk-based deposit insurance is analyzed in Section 3.5). The key limitation of retail deposits is that they are scarce: the bank is endowed with a fixed deposit base of $D < 1$. Note that, in this model, "retail deposits" can be seen as a metaphor for most types of *long-term funds* used by a bank. See more detailed discussion in Section 4.3.

2. "*Wholesale financiers*" are sophisticated but *short-term.* They can monitor the bank at a cost. Monitoring may produce information on date 2 realization before date 1. Wholesale financiers can use that information in making roll-over decisions.

   Wholesale financiers are willing to lend to the bank any amount of funds at date 0 against real expected return ρ. Parameter ρ reflects the return on alternative use of wholesale financier's money, and can be interpreted as funding liquidity conditions. The bank's project is more valuable than alternatives, so that initial funding is always available: $1 \leq \rho < pX$.

   The amount of wholesale funding attracted by the bank is denoted W. Since the maximum investment size is 1, $W \leq 1 - D$. Wholesale funding needs to be refinanced at date 1. If wholesale financiers refuse to roll over, the bank is forced into liquidation. The interest rate on wholesale funding is denoted R. We assume that R is set from date 0 to date 2. This allows the bank to avoid being held up by wholesale financiers at date 1 (cf. von Thadden, 1995). The payoff to wholesale financiers in date 1 liquidations is determined by the liquidation value $L(D + W)$ and their creditor seniority.

Monitoring A wholesale financier can obtain information on the bank's date 2 project realization by monitoring the bank. Monitoring takes place in between dates 0 and 1. The financier chooses the intensity of monitoring $m : 0 \leq m < 1$. She incurs cost $C(m)$ ($C(0) = 0$, $C(1) = \infty$, $C'(0) = 0$, $C''(m) > 0$). She then receives a *correct* signal of date 2 realization with probability m. That is, when monitoring succeeds, the financier obtains precise information of bank project quality. The financiers receive no signal at all with probability $1 - m$. In that case the financier knows that monitoring failed, and remains with information on prior probability of success p only.

Seniority The seniority of wholesale financiers relative to retail depositors in date 1 liquidations is described by the share s of liquidation value they receive ($0 \leq s \leq 1$). In early liquidations, wholesale financiers receive $sL(D + W)$ while retail depositors $(1 - s)L(D + W)$. Higher s represents a higher creditor seniority of wholesale financiers relative to retail depositors. Note that s describes the *effective* seniority of wholesale financiers. In practice, effective seniority is determined by a range of contractual choices: formal seniority, collateralized of funding, first-come-first-served rules, and official resolution options expected to be applied in case of bank failure.

Continuation For determinacy, we assume that at date 1 all agents marginally prefer a bank's continuation to liquidation when otherwise indifferent. Note that, since $L < 1$, bankers receive nothing in date 1 liquidations, and will therefore always prefer continuation. Retail depositors are set up as passive agents who always remain with the bank until date 2. Therefore, in this model, date 1 liquidations can only be triggered by short-term wholesale financiers. Finally, we focus on the case when the amount of wholesale funding attracted by the bank is not too small compared to the liquidation value:[4]

$$pW > L \tag{1}$$

We analyze the "bright side" model in three steps. First, we consider the basic case of a bank funded by retail deposits only. Second, we introduce wholesale funds and show their positive effect on social welfare in a constrained optimum. Finally, we model the equilibrium resulting from private choices of banks and wholesale financiers, and show that its outcome is consistent with the maximization of social welfare.

2.2 Retail deposits only

Consider first a bank funded by retail deposits only. Then, its volume of initial investment D is lower than maximum possible 1. Maintaining spare investment capacity is inefficient, because the bank's project has a positive net present value.

Furthermore, the bank always continues until date 2. This is because bankers are at least indifferent when choosing between continuation and liquidation at date 1, while retail depositors are uninformed and passive. This means that bad projects are not terminated at date 1 (which would preserve liquidation value L) but continue until date 2 returning 0. This is the second source of inefficiency.

Overall, the net present value of the bank's investment when financed with retail deposits only is:

$$\Pi_{Dep} = D(pX - 1) \tag{2}$$

[4] This single assumption, while mildly restrictive, allows to keep results easily tractable. In particular, it assures that wholesale financiers are not repaid in full in date 1 liquidations:

$$WR > L(D + W)$$

Even more strongly, (1) implies that

$$pWR > L(D + W)$$

which rules out outcomes when uninformed senior wholesale financiers *always* prefer to liquidate the bank at date 1 to receive $L(D + W)$ rather than wait until date 2 when they obtain expected pWR. This captures the stylized fact that "no news is good news" and absent negative information bank runs should be uncommon.

2.3 Wholesale funds: Welfare maximization

Now consider a bank that also attracts wholesale funds in the amount W. In this section, we derive the benchmarks for what would be the socially optimal monitoring and continuation decisions of wholesale financiers and the amount of wholesale funds attracted by a bank.

Consider first the continuation decision. At date 1, if monitoring was successful, a bad bank (which yields 0 at date 2) needs to be liquidated to preserve L. A good bank (which yields X at date 2) needs to be refinanced. When monitoring was unsuccessful, so the bank's project quality is unknown, a bank also needs to be refinanced since $Xp > L$.

Consider now the optimal intensity of monitoring, m^*, and the optimal amount of wholesale funds, W^*. The monetary value of social welfare:

$$\Pi = (D + W)\,(pX + m(1 - p)L - 1) - C(m) \tag{3}$$

is maximized for

$$W^* = 1 - D$$

so that a bank uses the maximum possible amount of wholesale funds and the complete initial investment opportunity of 1 is used, and for m^* given by

$$C'(m^*) = (1 - p)L \tag{4}$$

Comparing (3) with (2) highlights the beneficial effects of the use of wholesale funds: higher investment volume $D + W$ instead of D, and preserving the liquidation value of some bad banks $m^*(1 - p)L$ at the cost of monitoring $C(m^*)$.

2.4 Wholesale funds: Private equilibrium

We now derive equilibrium private choices of banks and wholesale financiers, and compare them with the socially optimal outcome.

Wholesale financiers Consider first the choices of wholesale financiers. They take decisions on the intensity of monitoring and on continuation (whether to roll over funds or liquidate the bank). Note immediately that their continuation decision is in line with the social optimum. If monitoring was successful, wholesale financiers have incentives to liquidate bad banks to receive $sL(D+W)$, and to roll over funding to good banks to receive WR. When monitoring was unsuccessful, uninformed wholesale financiers choose to roll over funding since, by (1), $pWR > sL(D+W)$.

Consider now the monitoring decision. In choosing the intensity of monitoring m, wholesale financiers maximize:

$$\Pi^W = pWR + m(1-p)sL(D+W) - C(m)$$

which obtains their private choice of monitoring intensity m^W given by:

$$C'(m^W) = (1-p)sL(D+W) \tag{5}$$

Observe from (4) and (5) that $m^W = m^*$ for $s = 1$ and $D+W = 1$. This means that wholesale financiers choose the optimal intensity of monitoring when they are senior creditors at the refinancing stage and the amount of wholesale funding is the maximum possible. The intuition for this outcome is that being senior allows wholesale financiers to fully internalize the benefits of monitoring: preserved liquidation value $L(D+W)$ which is higher for a higher use of wholesale funds. Optimal high seniority of wholesale financiers is an important result as it describes the nature of optimal contracting arrangements between the bank and short-term wholesale financiers.

Banks The bank takes decisions on the amount of wholesale funds W to attract and on the creditor seniority s to offer them. The bank's surplus is:

$$\Pi^B = p\left[D(X-R_D) + W(X-R)\right] \tag{6}$$

The interest rate R demanded by competitive wholesale financiers, obtained from their zero-profit condition, is:

$$R = \frac{W\rho + C(m^W) - m^W(1-p)sL(D+W)}{Wp}$$

Lemma 1 Π^B *increases in* s *and* W*.*

Proof. See Appendix. ■

The intuition for Lemma 1 is as follows. Π^B increases in s because R decreases in s: as wholesale financiers receive a larger share in early liquidations, the amount needed to compensate them in successful outcomes falls. Π^B increases in W because the bank is able to invest more funds, while at the same time the cost of monitoring per unit of wholesale funds used falls.

It follows directly from Lemma 1 that a bank acting in its own private interests will choose the maximum possible $W = 1 - D = W^*$ and $s = 1 = s^*$, consistent with the socially optimal outcome. We can now formulate the main result of this section. It describes the benchmark "bright side" effects of bank wholesale funding.

Proposition 1 *In the benchmark "bright side" case, the wholesale financiers' monitoring and continuation decision, and the banks' decisions on the amount of wholesale funds to use and their creditor seniority, are all in line with the constrained social optimum. In equilibrium, the amount of wholesale funds used by a bank is the maximum possible:* $W^* = 1 - D$*, wholesale funds are senior:* $s^* = 1$ *so that all benefits of monitoring are internalized, and the investment of wholesale financiers in monitoring* m^* *is given by* $C'(m^*) = L(1-p)$*.*

3 The Dark Side of Wholesale Funding

We now turn to the analysis of the "dark side" of bank wholesale funding. Specifically, in this section we show how a plausible and minor change to the "bright side" CK-style setup of Section 2 can significantly alter its results.

To model the "dark side" of wholesale funding, we introduce an additional source of information available to wholesale financiers. We assume that even when monitoring was unsuccessful (i.e., when it did not produce information about date 2 realization, either because of low investment in monitoring or merely by bad luck), wholesale financiers still obtain a free but *noisy* signal of date 2 realization in advance of date 1. That signal is best interpreted as a piece of publicly available information relevant to the bank's fundamentals but not perfectly so. Despite that the signal is free, it is complex to interpret, and therefore is not received by retail depositors.

We show that such a seemingly minor twist can generate outcomes that are contrasting to those of the "bright side" CK-style setup. The presence of a costless but noisy signal lowers the incentives of wholesale financiers to monitor, and gives them excess incentives to liquidate banks based on overly noisy public information. These distortions are stronger when wholesale financiers are made senior claimants to the liquidated assets. The reason is that they are relatively protected in date 1 liquidations. After liquidation they are entitled to a larger share of the smaller liquidated value, at the expense of passive depositors. We show that, as a result, the incentives of opportunistic wholesale financiers are most aligned with the social optimum when they are assigned intermediate (rather than high) creditor seniority at the refinancing stage – different from the CK results.

We further address the incentives of banks. We show that banks, because of their limited liability, do not fully internalize the externalities of their contracting with short-term wholesale financiers on retail depositors (or other providers of long-term funds). Consequently, they may choose to assign too high seniority to short-term wholesale funds. This would lead to excess noisy liquidation in equilibrium, and bear close resemblance to effects observed during the recent turmoil. Moreover, comparative statics analysis shows that both the risk of noisy liquidation by wholesale financiers and the incentives of banks to borrow funds from them opportunistically – the "dark side" of wholesale funding – dominate in "modern" banks characterized by arm's length and tradable assets and an active combination of retail and wholesale funds in the liability structure.

3.1 Additional feature: A noisy public signal

To model the "dark side" of wholesale funding, we add a free but noisy signal on bank quality. The free signal is received by wholesale financiers after monitoring but before date 1. This sequence reflects the fact that the choice of intensity of monitoring is a strategic (anterior) decision, and that it takes time to build up monitoring capacity. Gorton (2009) for example describes how market participants in the subprime mortgage crisis were caught unprepared to cope with the sudden information requirements for understanding, valuing, and trading securities that were previously information-insensitive. Also observe that while monitoring is assumed to be precise if successful, the free signal is noisy: widely available public information is of lower quality than that produced through dedicated private investigation.

We specify the signal to have the same distribution of outcomes as that of the underlying project, but providing only noisy information on the final outcome. Formally, the signal takes two values: "positive" or "negative", and is characterized by a precision parameter θ ($0 \leq \theta \leq 1$; $\theta = 0$ for uninformative; $\theta = 1$ for precise). The probability of receiving a positive signal is p (same as for X at date 2); conditional on that the probability of getting X at date 2 is $[p + \theta(1 - p)]$, and that of getting 0 is $[(1 - p) - \theta(1 - p)]$. The probability of a negative signal is $1 - p$ (same as for 0 at date 2); conditional on that the probability of getting X at date 2 is $[p - \theta p]$, and that of getting 0 is $[(1 - p) + \theta p]$.

The principal impact of the noisy signal on the mechanics of the model is as follows. Recall that without such a signal, uninformed wholesale financiers (who did not receive precise information from monitoring) always rolled over funding at date 1. That was consistent with both welfare maximization ($pX > L$) and their private incentives ($pWR > sL(D+W)$). Now, however, uninformed wholesale financiers may choose not to roll over funding after receiving a negative but noisy signal. This paves the way for early liquidations of banks based only on free but noisy information ("noisy liquidations").

We analyze the model in five steps. First, we derive the benchmark for the socially optimal use of the noisy costless signal. Second, we analyze the private incentives of wholesale financiers. Third, we show that, with the risk of jittery noisy liquidations, it is socially optimal that wholesale financiers be assigned intermediate (rather than high) creditor seniority. Fourth, we study incentives of banks, and show how they can deviate from the socially optimal ones. Finally, we analyze options for policy response.

3.2 Welfare maximization

We start by outlining the benchmark socially optimal decisions on continuation, monitoring, and the use of wholesale funds in the presence of a free but noisy signal on bank project quality.

Noisy liquidations Consider the optimal use of a noisy public signal. When monitoring was successful, bank quality is known precisely. The noisy signal cannot add to the fundamental information produced through monitoring. As before, good banks need to be refinanced while bad banks need to be liquidated.

When monitoring was unsuccessful, without the noisy signal, continuation was always optimal at date 1. The noisy signal refines date 1 probabilities of success or failure at date 2. For a positive noisy signal, the posterior of success at date 2 increases to $p + \theta(1 - p)$. It remains optimal that the bank is refinanced. However, for a negative noisy signal, the posterior of success at date 2 falls to $[p - \theta p]$. There are two possible outcomes. If the precision θ of the noisy signal is low so that $[p - \theta p]\, pX \geq L$, it is still optimal to refinance the bank (as was in the case of no information). In this case the noisy signal is effectively disregarded: it has no impact on the continuation and by implication on any other decisions. However, if the precision of the noisy signal θ is high enough so that $[p - \theta p]\, pX < L$, it is optimal to liquidate the bank based *solely* on a noisy signal. The threshold value of θ is

$$\theta^* = 1 - \frac{L}{p^2 X} \tag{7}$$

Note that, unless $\theta = 1$, some good banks will suffer noisy liquidations as well.

Monitoring and use of wholesale funds Now consider how the availability of a costless noisy signal affects the optimal intensity of monitoring and the optimal amount of wholesale funds to use. The impact depends on the precision of a noisy signal. Recall that, when its precision is low, $\theta \leq \theta^*$, it is optimal to disregard the noisy signal. As a consequence, the maximization problem is the same as in the benchmark case (3). The optimal amount of wholesale funds to use is the maximum possible $W^* = 1 - D$ and the optimal amount of monitoring is m^* as defined by (4).

When the precision of the noisy signal is high, $\theta > \theta^*$, it is socially optimal to use the noisy signal, and liquidate the bank when it is negative. The monetary value of social welfare in this case is:

$$\Pi_{Liq} = (D + W)\,(m\,[pX + (1-p)L] + (1-m)\,[p\,[p + \theta(1-p)]\,X + (1-p)L] - 1) - C(m) \tag{8}$$

The term $m\,[pX + (1-p)L]$ is the payoff to successful monitoring, similar to (3). The term $(1-m)\,[p\,[p + \theta(1-p)]\,X + (1-p)L]$ is novel: it is the payoff from using the noisy signal when monitoring was unsuccessful (and liquidating the bank upon a negative signal). The probability of a positive signal is p; conditional on it the bank is refinanced and yields X with probability $[p + \theta(1-p)]$. The probability of a negative signal is $(1-p)$; the bank is liquidated to preserve L.

As before, the social welfare (8) is increasing in W, so that it is optimal to use as much wholesale funding as possible: $W^*_{Liq} = 1 - D = W^*$. The optimal intensity of monitoring m^*_{Liq} is given by:

$$C'(m^*_{Liq}) = p\,(1-p)\,(1-\theta)\,X \tag{9}$$

Observe that $m^*_{Liq} < m^*$. This is easy to verify by applying the condition for using the noisy signal $[p - \theta p]\, pX < L$ to (4) and (9). The intuition is that the availability of a noisy but free signal makes the information obtained through costly monitoring less valuable.

3.3 Wholesale financiers: Private incentives and socially optimal seniority

Now consider private choices of wholesale financiers.

Noisy liquidations When monitoring was successful, as before, wholesale financiers had incentives to follow its outcome: refinance known good banks and force liquidation of bad ones. When monitoring was unsuccessful, uninformed wholesale financiers can use the noisy public signal. Upon a negative noisy signal, their expected continuation payoff is $[p - \theta p]\, WR$. Their liquidation payoff is $sL(D+W)$. For wholesale financiers, it is privately optimal to follow a noisy signal and liquidate the bank for

$$sL(D+W) > [1-\theta]\, pWR \tag{10}$$

Expression (10) can be interpreted either as sufficiently high precision of the noisy signal:

$$\theta > \theta^W = 1 - \frac{sL(D+W)}{pWR} \tag{11}$$

or as sufficiently high seniority of wholesale financiers:

$$s > s^W = \frac{(1-\theta)\, pWR}{L(D+W)} \tag{12}$$

Note that the private threshold θ^W can be either above or below the socially optimal threshold θ^* depending on the value of s. When s is low and $\theta^W > \theta^*$, wholesale financiers have insufficient private incentives to liquidate banks. When s is high and $\theta^W < \theta^*$, wholesale financiers have excess private incentives to liquidate banks based solely on noisy information. However, observe that wholesale financiers always have excess incentives to liquidate banks based on noisy information when they are senior (s is close to 1): $\theta^W_{s=1} < \theta^*$.

From this point on, we will focus on the case with the richest interpretations. We consider the case when private and public incentives to liquidate banks based on noisy information diverge. Specifically, we consider θ in the interval $\theta^W_{s=1} < \theta < \theta^*$. This describes the environment where the noisy public signal is not very informative, so that from the social welfare perspective it is optimal to disregard it. However, the signal is still informative enough to be used by senior wholesale financiers, and to trigger "noisy" bank liquidations.

Monitoring Consider now the monitoring choices of wholesale financiers. Recall that when wholesale financiers are sufficiently junior, $s \leq s^W$, they disregard the noisy signal. Therefore, their private choice of monitoring intensity is the same as the benchmark m^W (5).

However, when wholesale financiers are sufficiently senior, $s > s^W$, they have incentives to use the noisy public signal and liquidate the bank when it is negative. Then, in choosing monitoring intensity, they maximize

$$\Pi^W = m\left[pWR + (1-p)sL(D+W)\right] + (1-m)\left[p\left[p+\theta(1-p)\right]WR + (1-p)sL(D+W)\right] - C(m) \tag{13}$$

which obtains:

$$C'(m^W_{Liq}) = p\,(1-p)\,(1-\theta)\,WR_{Liq} \tag{14}$$

Observe that, unlike in expression for m^W (5), s does not enter directly into the specification of m^W_{Liq} (14). Rather, it affects m^W_{Liq} indirectly through R_{Liq}. To see that in detail, consider the interest rate charged by competitive financiers:

$$R_{Liq} = \frac{W\rho + C(m^W_{Liq}) - (1-p)sL(D+W)}{m^W_{Liq}Wp + (1-m^W_{Liq})\left[p+\theta(1-p)\right]Wp}$$

As s increases and wholesale financiers receive more in date 1 liquidations, they require less compensation in case of date 2 success: in equilibrium, R_{Liq} decreases in s. Therefore, since m^W_{Liq} increases in R_{Liq}, it decreases in s. This contrasts with the benchmark case without the noisy signal where m^W (5) increased in s. The intuition behind this result is that senior wholesale financiers who can use noisy signals become less interested in the bank's long-term value. Indeed, they can easily liquidate the bank on mild negative news before the long-term value is realized, at only very low private cost.

This makes $s = s^W$ a threshold point not only for the liquidation decision, but also for the choice of intensity of monitoring of wholesale financiers. The properties of s^W are summarized in the following lemma:

Lemma 2 *Consider s^W given by (10).*

1. For $s \leq s^W$ wholesale financiers never liquidate a bank based on noisy information and the intensity of their monitoring increases in seniority: $\partial m^W / \partial s > 0$, consistent with the benchmark "bright side" of bank wholesale funding.

2. For $s > s^W$ uninformed wholesale financiers choose to liquidate a bank following a negative noisy signal and the intensity of their monitoring decreases in seniority: $\partial m^W_{Liq} / \partial s < 0$, contrasting with the "bright side" benchmark.

3. The intensity of monitoring chosen by wholesale financiers is maximized for $s = s^W$, that is, for an intermediate value of their seniority.

Proof. See Appendix. ■

The contrasting effects of seniority on the behavior of wholesale financiers with and without the noisy public signal are illustrated in Figure 1. The left panel shows that, in the benchmark case without a noisy public signal, the monitoring effort of wholesale financiers increases monotonically in their creditor seniority. The right panel depicts the same relation, but with the noisy signal. There, for low values of seniority, wholesale financiers disregard the noisy signal so their actions are identical to those in the benchmark case. However, when seniority exceeds the threshold value $s = s^W$, wholesale financiers start to reduce monitoring efforts in response to higher seniority.

Optimal use and seniority of wholesale funds We now take the incentives of wholesale financiers identified in Lemma 2 as given, and ask what would be the resulting *socially optimal* use (W) and seniority (s) of wholesale funds. The key result on the optimal use of wholesale funds by banks is as follows:

Proposition 2 *Consider the case with possible welfare-reducing noisy liquidations,* $\theta^W_{s=1} < \theta \leq \theta^*$*. Then the socially optimal creditor seniority of wholesale financiers is* $s = s^W$ *(12). This is the intermediate level of seniority, lower than the "bright side" benchmark* $s = 1$*. Setting* $s = s^W$ *fully aligns the continuation decision of wholesale financiers with the socially optimal: there are no noisy liquidations. At the same time,* $s = s^W$ *maximizes the intensity of monitoring privately chosen by wholesale financiers, albeit at the level below the social optimum:* $m^W(s^W) < m^*$*. The optimal amount of wholesale funds remains the highest possible* $W = 1 - D = W^*$*.*

Point s^W can be thought of as the highest seniority of short-term wholesale funds that does not give rise to early liquidations. For $s < s^W$ higher seniority increases the intensity of monitoring chosen by wholesale financiers. After that, for $s > s^W$, fundamentally uninformed wholesale financiers will start liquidating banks based on a negative noisy signal. That is not socially optimal. Moreover, for $s > s^W$, the monitoring effort of wholesale financiers starts to decrease in higher seniority. In effect, for $s > s^W$, higher seniority of wholesale financiers translates not into increased intensity of monitoring (as was in the "bright side" case) but purely into excess liquidations – and less monitoring.

The fact that intermediate rather than high seniority of wholesale funds is optimal in order to prevent excess liquidations of banks based on overly noisy public information is a key departure from the CK-type result describing the "bright side" of wholesale bank funding.

3.4 Comparative statics

Lemma 2 and Proposition 2 offer interesting cross-sectional predictions on (a) the risk of excessive noisy liquidations in different types of banks, and (b) the socially optimal seniority of short-term wholesale funds in different types of banks. Note that (a) and (b) are just two sides of the same coin: certain bank characteristics that predict a higher risk of excessive noisy liquidations also prescribe as socially optimal an assignment of lower seniority to wholesale funds. This would increase the losses that wholesale financiers incur in early liquidations, and thus reduce their incentives to liquidate based on overly noisy information.

Consider inequalities (10) and (12). It is more likely that they are satisfied, so that the risk of noisy liquidations by short-term wholesale financiers is higher, when:

- θ, the "precision" of the public noisy signal on bank project quality, is higher (but not perfect).
- The bank's liquidation value L is higher.

Also, from (10), the risk of noisy liquidations is higher when s, the actual seniority of short-term wholesale funds, is higher. However, this parameter does not vary much across banks and is less interesting in our comparative statics analysis.

The above two predictions suggest an interesting distinction between (1) "traditional" banks holding relatively relationship-based small business loans (which are associated with low θ and L) and (2) "modern" banks holding mostly tradable arm's-length assets (which are associated with relatively higher liquidation value L, and relatively more relevant public information on quality – high θ – because of the availability of secondary market prices and credit ratings).

In both types of banks, the "bright side" benefit as modeled by CK is at work: higher seniority to wholesale funds encourages them to monitor. However, the "dark side" cost that works in the opposite direction is likely to be greater for "modern" banks. In "traditional" banks characterized by low θ and L, according to the comparative statics predictions above, the "dark side" of wholesale funding has a relatively small impact and is likely dominated by the "bright side" benefits. In this case, the CK model provides a good approximation of reality. In "modern" banks, however, because of high θ and L, the risk of liquidations based on noisy public information is higher and can offset and sometimes outweigh the "bright side" benefit. In this case, the "dark side" effect cannot be neglected.

Finally, comparative statics can also show that the risk of noisy liquidations by short-term wholesale funds is higher when wholesale funds W is low relative to retail deposits D. Note that "retail deposit" should be broadly interpreted as any type of long-term funding. In the case of Northern Rock, besides 27 percents of customer deposits, D would also include contractually long-term securities such as equity, securitized notes, and covered bonds, which accounted for another 50 percents of the bank's liabilities. Contrary to media perceptions, in Northern Rock short-term funding W was not very high relative to long-term funding D. This prediction suggests, interestingly, that long-term funds D, while being a seemingly safe liability by themselves, also serve as an exit buffer for short-term wholesale financiers and make liquidations less costly for them, increasing the risk of overly noisy liquidations and reducing the wholesale financier's monitoring incentives.

3.5 Banks' incentives to use wholesale funds

The previous section has established socially optimal seniority for opportunistic wholesale financiers: an intermediate creditor seniority s^W that brings their choices closer to the social optimum. However, in practice the decisions on creditor seniority are taken by a bank with the objective of maximizing its private surplus. In this section, we study the incentives of banks, and ask whether unconstrained bank choices of s^W can deviate from the social optimum.

They key mechanism behind this section's results is that banks are not fully punished for their overly risky contracting with short-term wholesale financiers. In short, deposits and other long-term funds are generally not efficiently priced according to the liquidity risk modelled in this paper. Interest rates on insured deposits are risk-insensitive. Interest rates on long-term debts are fixed within the tenor of the contract, and banks cannot commit not to attract secondary sources of funding after the long-term debts are invested (a sort of liability-side "risk-shifting" behavior a la Myers and Majluf, 1984). Therefore, a higher risk of non-repayment may not translate into a correspondingly higher interest rate punishment for a bank.

Bank's choice of seniority for wholesale financiers Consider the impact of offering wholesale financiers a higher creditor seniority than is socially optimal: $s > s^W$. Recall that the social cost of this action is (a) inefficient noisy liquidations and (b) lower intensity of monitoring by wholesale financiers. Let us now consider private costs and benefits for the bank. The bank's private cost is similar to the social one: losses when good projects are abandoned in early liquidation. However the bank also has a private benefit. Offering higher seniority to wholesale financiers reduces the interest rate R charged by them. As long as the interest rate on long-term funding (e.g., deposits) R_D is fixed, this leads to an increase in a bank's surplus. When the net effect of higher seniority on a bank's surplus is positive (the lower interest rate effect dominates the higher risk of liquidation effect), the bank has private incentives to offer too high seniority to short-term wholesale financiers.

To see this formally, compare the bank's surplus from selecting $s = s^W$ versus some $s > s^W$.

For $s = s^W$ we have:

$$\Pi^B_{s=s^W} = p\left[D(X - R_D) + W(X - R)\right] \tag{15}$$

where

$$R = \frac{W\rho + C(m^W) - m^W(1-p)sL(D+W)}{Wp}$$
$$s = s^W$$

For $s > s^W$ we have[5]:

$$\Pi^B_{Liq} = \big[p - (1-m^W_{Liq})p(1-\theta)(1-p)\big]\,[D(X-R_D) + W(X-R_{Liq})] \tag{16}$$

where

$$R_{Liq} = \frac{W\rho + C(m^W_{Liq}) - (1-p)sL(D+W)}{W\Big(p - (1-m^W_{Liq})p(1-\theta)(1-p)\Big)}$$

Compare $\Pi^B_{s=s^W}$ and Π^B_{Liq}. Observe that Π^B_{Liq} incorporates a lower probability of a bank's success: it is reduced by the probability of inefficient liquidations $(1-m^W)p(1-\theta)(1-p)$. As a result there is a discrete fall in Π^B as soon as s exceeds s^W as a bank becomes subject to inefficient early liquidations. The value of that decline is

$$\Delta = (1-m^W)p(1-\theta)(1-p)\,[D(X-R_D) + W(X-R)] \tag{17}$$

However, after the drop at s^W, $\Pi^B_{s>s^W}$ can start increasing in s. The reason is that a higher s gives wholesale financiers more in date 1 liquidations (at no expense for the bank), and allows the bank to repay them less in case of success at date 2. To see this formally, consider

$$\frac{d\Pi^B_{Liq}}{ds} = -\frac{dR_{Liq}}{ds}\big[p - (1-m^W_{Liq})p(1-\theta)(1-p)\big]\,W + \frac{dm^W_{Liq}}{ds}p(1-\theta)(1-p)\,[D(X-R_D) + W(X-R_{Liq})] \tag{18}$$

The first term on the right-hand side is positive: it reflects the reduction in the

[5] Note that m^W and R are continuous at s^W: $m^W(s^W) = m^W_{Liq}(s^W)$ and $R(s^W) = R_{Liq}(s^W)$. This is easy to show formally by substituting expressions for m^W (5), s^W (12), and m^W_{Liq} (14). The intuition is that at s^W wholesale financiers are indifferent between using and not using the noisy signal and therefore marginal changes in s lead to marginal changes in m and R.

interest rate that the bank has to pay on short-term wholesale funds: $dR_{Liq}/ds < 0$. The second term on the right-hand side is negative: $dm_{Liq}/ds < 0$ as with higher s wholesale financiers lose their incentives to monitor the bank, leading to more ineffective liquidations.

Either effect can dominate depending on parameter values. For example, one can verify that for a very low L the term dR_{Liq}/ds is so low that the second term dominates and $d\Pi^B_{Liq}/ds$ is negative. Then the bank would never choose $s > s^W$. Yet, conversely, when the impact of s on m^W_{Liq} is very small, the second term is so low that the first term dominates and $d\Pi^B_{Liq}/ds$ is positive. In this case, should the initial fall in a bank's surplus Δ be outweighed by a subsequent increase of Π^B_{Liq} as s becomes high enough, the bank would have incentives to assign wholesale financiers a higher seniority $\hat{s} > s^W$ than is socially optimal.

It is this latter case that corresponds to the *dark side* of wholesale bank funding. There, banks opportunistically assign too high seniority to wholesale financiers in order to benefit from lower interest rates, while senior wholesale financiers, in turn, opportunistically liquidate banks based on overly noisy public information. Both decisions are not socially optimal. The existence of such "dark side" equilibrium is formally established as follows:

Proposition 3 *There exist parameter values of θ, L, D, W and ρ such that for some $\hat{s} > s^W$: $\Pi^B_{Liq}(\hat{s}) > \Pi^B_{s=s^W}$ so that a bank has incentives to assign higher creditor seniority to wholesale financiers than is socially optimal.*

Proof. See Appendix. ■

We now turn to comparative statics. In order to formulate tractable results, we require an additional simplification. We focus on the case when m_{Liq} is relatively unaffected by changes in exogenous parameters that we are going to vary. This is the case, for example, when $C(m)$ is relatively flat. Otherwise minor changes in exogenous parameters could lead to significant changes in m_{Liq} (e.g., it may suddenly turn into zero) which would significantly complicate the analysis.

Under this condition, interest rate savings are more likely to offset increased risk of bank failure in $d\Pi^B_{Liq}/ds$, so that a bank has higher incentives to choose $s > s^W$ over s^W, when:

- The precision of a noisy signal on bank project quality θ is higher (but not perfect). The intuition is that a higher θ makes the liquidation decisions more precise and therefore less costly: it is easy to see in (17) that a higher θ reduces Δ. One can also observe in (18) that a higher θ increases a multiplier of dR_{Liq}/ds, leading to a higher $d\Pi^B_{Liq}/ds$.
- The bank's liquidation value L is higher. To verify this observe first that L does not affect Δ. The reason is that although L enters expressions for R and m^W, it does so proportionately to s^W. Yet s^W itself is inversely proportional to L (as seen in (12)). Therefore $d\Delta/dL = 0$. At the same time a higher L increases the value of dR_{Liq}/ds leading to a higher $d\Pi^B_{Liq}/ds$.

Observe that these predictions are reinforcing the comparative statics observed in the incentives of providers of wholesale funds. Precisely the same characteristics of "modern" banking which increase the risk of "noisy" liquidations by wholesale financiers (relevant public signals on project quality and a high liquidation value) *also* make banks more likely to assign the providers of wholesale funds with inefficiently high creditor seniority.

Another observation is an extension. Consider the hypothetical situation where banks simultaneously choose type of assets in the portfolio and funding. Then, the comparative statics suggests clustered choices. Bank that choose arm's length assets would also use more short-term wholesale funding. Banks that choose to engage in relationship lending would also use more stable deposits. This conjecture is in line with Kashyap, Rajan, and Stein (2002) and Song and Thakor (2007) and supported empirically by Berlin and Mester (1999) and Berger et al.(2005).

We will not formulate results for the impact of funding structure (D and W) on banks' incentives. The reason is that those are ambiguous. Higher D and W increase both losses due to noisy liquidations Δ and interest rate savings dR_{Liq}/ds. Depending on parameter values, either effect can dominate.

To close the solution, we verify that the bank always uses the maximum amount of wholesale funds $W = 1 - D = W^*$. Lemma 1 proved that Π^B increases in W for $s \leq s^W$. It is straightforward to obtain through similar derivations that Π^B_{Liq} also increases in W (there is an additional effect that as m^W_{Liq} falls in W the probability of noisy liquidations falls, increasing Π^B_{Liq}). The intuition, as before, is that using a higher amount of wholesale funds allows banks to utilize more of the valuable investment opportunity and to reduce the per-unit cost of monitoring.

3.6 Policy response: A Pigouvian tax

Our model has identified two inefficiencies in the banks' use of wholesale funds:

- Wholesale financiers can liquidate banks based on overly noisy public signals;
- Banks can assign too high seniority to wholesale financiers, increasing risk of inefficient early liquidations.

In this section we discuss how regulators can bring the choices of banks and wholesale financiers closer to the social optimum. The insight that security design may be a substitute to complete contracts can be traced back to Aghion and Bolton (1992) and Dewatripont and Tirole (1994). Our model suggests that a possible solution is a Pigouvian tax on the use of short-term wholesale funds to align banks' incentives with the social optimum. The tax can be implemented as risk-based deposit insurance premia enforced by the FDIC, or insurance premia in Kashyap, Rajan, and Stein (2008) capital insurance or Perotti and Suarez (2009) liquidity insurance.

Recall that the private incentives of banks are misaligned because they do not internalize all the negative effects of risky senior short-term wholesale funding on depositors (or other providers of long-term funds). As our model shows, by offering a higher s to wholesale financiers, the bank is able to save on its total interest rate payments by paying a lower rate on short-term wholesale funds while the deposit interest rate is risk-insensitive. Authorities can attempt to restore a bank's incentives to social optimal by charging the bank Pigouvian taxes (possibly in the form deposit insurance premia) for this externality.

Consider Π^B_{Liq}: the bank's profit function at $s > s^W$ (16). Assume for simplicity that the effects of wholesale financiers' monitoring choices are second-order: m is fixed. Interest rate savings from choosing $s > s^W$ are $(1-p)(s-s^W)L(D+W)$. These savings are a pure negative externality as they are obtained at expense of higher repayment risk on deposits. To make the bank internalize this negative externality these savings could be removed by charging the bank a tax of

$$T = (1-p)\max\{(s-s^W); 0\}L(D+W) \tag{19}$$

The tax would counterbalance a bank's incentives to choose $s > s^W$ but would not affect its choices on $s \leq s^W$, therefore leading to a socially optimal outcome $s = s^W$. The comparative statics on the optimal T is as follows.

First, the formula points to a higher tax for more risky banks (higher $1-p$).

Second, the tax should be higher for banks that assign higher *effective* seniority s to wholesale funds. Note that, under a sequential service rule, wholesale funds with shorter remaining maturity enjoy higher *effective* seniority than those with longer remaining maturity. Therefore, the formula suggests that the higher tax on for the shorter-maturity wholesale funds. (Cf. Perotti and Suarez, 2009, who advocate charging banks based on the maturity mismatch in their funding structure.)

Third, the tax should ideally depend on a bank's *optimal* seniority of wholesale funds s^W. The authorities can find some rough proxy for s^W. Our model predicts that banks holding arm's length assets are associated with a lower s^W and therefore should be taxed most heavily for the use of short-term wholesale funds. In contrast, banks with a high percentage of small business loans have a higher s^W and may be exempted from the tax.

Fourth, whereas deposit insurance premia are sometimes assessed only on the value of insured deposits, the proposed tax should be assessed based on a bank's total liabilities $D + W$. The reason is that while externalities are imposed on insured deposits, they are in fact proportional to the total value of liabilities.[6]

Finally, the tax should be higher for banks with more liquid balance sheets (i.e., higher L). This contrasts to the logic underlying models with coordination failures (e.g., Diamond and Dybvig, 1983) where a larger liquidity buffer could reduce the probability of bank runs and hence should be seen as an advantage. Yet our result reflects the fact that wholesale financiers usually withdraw ahead of retail depositors, therefore capturing most of the benefits of the larger liquidity buffer. As a result, greater assets liquidity reduces wholesale financiers' cost of exit in early liquidation, and by that encourages them to adopt liquidation strategies detrimental to retail depositors. Such effects, where higher buffers facilitate moral hazard of opportunistic agents, are similar in spirit to the "paradox of liquidity" identified by Myers and Rajan (1998).

4 Discussing the Model's Limitations

This section highlights some features and limitations of our model and discusses additional policy insights.

4.1 Relationship to Calomiris and Kahn (1991)

Our model of the dark side of bank wholesale funding is set up as an extension of the seminal Calomiris and Kahn (1991), which we take as a benchmark for the "bright side" of wholesale funding. The key CK insight used in this paper is that a bank's own debt

[6] Interestingly, this corresponds to the current FDIC policy that assesses deposit insurance premia based on a bank's "total deposits" (i.e., not only insured deposits but also uninsured ones that behave like wholesale funds, such as jumbo CDs). The stated reason for this FDIC policy is that it is technically difficult to separate insured and uninsured deposit accounts. Our model offers a deeper economic explanation: such a policy reduces banks' incentive to attract risky short-term wholesale funds such as jumbo CDs. Our model further suggest that the FDIC can do even better by including in the assessment base all other short-term liabilities, such as commercial paper and interbank borrowings, as well as long-term liabilities.

holders, when properly incentivised, can acquire private information by monitoring, and liquidate the bank in states where the liquidation value is higher than the continuation payoff.

At the same time, we make a number of expositional simplification to the original CK framework in order to focus on the most novel results. Two changes are relatively straightforward. First, we disregard the banker's "absconding game" that further reduced payoffs in the low-returns state of the CK model. Instead, we simply assume that the continuation payoff in the low-returns state is by itself low enough to *always* warrant intermediate liquidation if the future state is known. (This also rules out the "nuisance" repricing contract of CK that enabled the bank to avoid absconding – not present in our setup.)

Second, we exogenously limit the universe of financing contracts to simple debt. Debt was an endogenous result of CK. We recognize the consequent limitation that our model addresses the optimal design (seniority) of an exogenously-imposed bank debt contract (which however is indeed the one most commonly observed in banking firms), rather than optimal contract design in its more general form. We discuss scope for more complex financing contracts in Sections 4.5 and 4.6.

A third difference deserves a deeper discussion. Our model considers a single "sophisticated" financier, equivalent to the basic CK case of a single depositor. We abstract from effects surrounding multiple financiers – so the relationship to the general CK case of multiple monitoring depositors needs to be clarified. Recall the key assumptions of that framework: many potential monitors, low costs of monitoring, and sufficiently precise i.i.d. signals received by different monitors. The consequent result is that individual signals can be aggregated under the law of large numbers, offering a very precise estimate of the bank's future condition. Occasional "wrong positives" – negative individual signals for a bank in a good state that trigger individual withdrawals – can be addressed through partial reserves.

How could a noisy public signal affect the CK framework with multiple depositors?

Our preferred way to think about this is through the prism of Morris and Shin (2002) who note distorting effects of freely available but imprecise public information on the use of private signals. Indeed, it is easy to observe the scope for inefficient bank runs when agents follow a noisy public signal rather than the outcomes of individual information gathering that are significantly more precise in aggregate. Such an outcome appears particularly natural when the noisy public signal is more informative than individual private signals (which is privately costly to collect), but less informative than the aggregate of private signals – mirroring our model's conclusion on the distorting effects of a relatively precise but still noisy public signal.

4.2 Modelling wholesale financiers

Our paper uses a number of convenient simplifications in modelling wholesale financiers. Most notably we considered a single competitive financier. The most natural consequence of having multiple financiers would be coordination failure between them at the refinancing stage (for example, of the type analyzed by Rochet and Vives, 2004). Coordination failures are an additional, yet already well analyzed, facet of the "dark side" of bank wholesale funding. By analyzing a single financier, we abstract from possible coordination failures, and highlight our new and stronger results that inefficient liquidations can occur even in the absence of coordination failures.

For modelling brevity, we have also explicitly ruled out any hold-up at date 1 by pre-determining the date 1 to date 2 interest rate in a manner similar to von Thadden (1995). Competition and interest-rate setting by wholesale financiers can be modelled more fully in the style of (1990) and von Thadden (2004). Such enhancements would not affect our key results.

Finally, some other dimensions of wholesale bank funding markets were also left outside of the scope of this paper. For example, interbank lending often represents a substantial share of wholesale funding of banks. Considering bank inter-linkages within the "dark side" framework could generate a richer picture of systemic effects, with implications, for example, for peer-monitoring (Rochet and Tirole, 1996) and contagion (Allen and Gale, 2000, Freixas et al., 2000, Acharya and Yorulmazer, 2007). We leave such applications for future analysis.

4.3 Long-term funds

This model has identified long-term bank funding with "retail deposits", arguing that such funding is passive (never withdraws at an intermediate date) and risk-insensitive (possibly due to deposit insurance). These two properties drove the main inefficiency in bank behavior: since the terms of long-term funding were fixed within the tenor of the contract, banks had incentives to subsequently attract overly risky secondary (short-term) sources of funds.

It is important to point out, however, that "retail deposits" of our model can be interpreted as a metaphor for a much wider range of—or, indeed, all—long-term funding instruments (such as equity, securitized notes, bonds, covered bonds, etc.). Indeed, these long-term non-depository funds share the same properties that were critical in our model: they cannot withdraw at an intermediate date, and therefore, the interest rate (or credit spread) is fixed after credit is extended to the bank; banks are unable to commit not to attract short-term funding after the long-term funds are locked in.

Therefore, the results of our model are relevant to a broader conflict of interest between short-term and long-term bank financiers. Indeed, the model can help us understand failures of financial institutions that had no retail deposits at all. For example, the run on "Bear Stearns" can be linked to the conflict of interest between short-term collateralized and long-term unsecured financiers. The former ran, recouping almost the face value of their investment, while leaving the latter with residual assets much diminished in value.

What the model does not consider however is the distinct role of outside equity. We have no misalignment between the incentives of bank managers and shareholders; the model only deals with a “banker” (owner-manager) that maximizes residual surplus.

We recognize that the conflict of interest between shareholders and managers can exist in practice, but see it as one beyond the scope of this paper, which has rather focused on an already-rich conflict of interest between the bank's owner-manager and different classes of debtholders.

4.4 A model of protected banking

The model does not consider possible government interventions during bank runs. Yet, during the recent financial turmoil, we have observed that authorities almost always intervene to prevent bank failures. The common method of intervention (such as in the case of Northern Rock or AIG) was to substitute wholesale outflows with central bank funds. In order to prevent bank failure, authorities effectively facilitated the exit of wholesale financiers, allowing them to withdraw upon a negative noisy signal without losses. In terms of the model, such bailouts correspond to increasing the wholesale financiers' liquidation payoff beyond sL. Such interventions would exacerbate moral hazard, resulting in very low levels of monitoring, runs based on exceedingly noisy public signals, and banks' overly reliance on short-term wholesale funding (which becomes effectively government-subsidized).

Yet, given the possible devastating effects of even a single bank failure on other parts of the financial system and on the real economy – such interventions appear unavoidable ex-post. What can be done to reduce the immense moral hazard created by almost-ceratin ex-post bailouts?

In our view, this paper provides a simple and viable answer. Interventions that exacerbate inefficiencies ex-post should be complemented by stronger ex-ante measures, such as the Pigouvian tax outlined in Section 3.6. Such a tax on short-term wholesale funding would reduce bank incentives to attract risky wholesale funding, and will therefore minimize the need for ex-post bailouts.

Interestingly, we believe that a tax on short-term wholesale funding would not only align ex-ante incentives of banks, but also enable a more effective policy response ex-post.

Recall that one of the common criticisms on the government response to the turmoil was the reluctance to write down the value of *any* bank debt claims, even subordinated ones. The apparent reason was that such write-downs could have exacerbated wholesale debt runs. If short-term wholesale funding is discouraged and banks shift to longer-term sources of funding, then the threat of wholesale runs will be less imminent (fewer funding matures during any given time interval). Hence authorities will be less constrained by financial stability concerns in writing down the value of bank debt claims.

The argument that short-term wholesale bank debt creates significant impediments for effective intervention ex-post and that bank funding structure should be adjusted to reduce ex-ante moral hazard and enable more effective ex-post intervention is close in spirit to the one raised by Calomiris (1999) ten years ago.

4.5 Debt contingent on the revelation of public signal

If the public signal was verifiable, one could improve on a simple debt financing contract and better align wholesale financiers' monitoring and liquidation incentives with the social optimum. This can be done in two ways. First, the financing contract could offer a higher creditor payoff conditional on a negative public signal than that conditional on a positive signal. This would compensate financiers who do not liqudiate on a negative public signal, and hence discourage liqudiations and increase incentives to monitor (to see this formally, observe that θ^W increases in R in (11)).

Second, the financing contract could incorporate features leading to lower effective seniority of wholesale financiers conditional on a negative public signal. One example could be a Flannery (2002)-type debt that converts into common equity (or, for our purposes, long-term debt) upon such a signal. Reduced effective seniority discourages liqudiations and increases incentives to monitor. An interesting point of comparison with Flannery (2005) would be that our model ephasizes that, optimally, only a portion of debt should be converted, for otherwise effective seniority could be too low and discourage ex-ante monitoring.

We do not undertake a deeper analysis of such securities beyond these basic considerations due to reservations on whether they are feasible in practice. The key problem is that even when the public signal is verifiable ex-post, it may be of the type that is impossible to predict in advance (e.g. it was impossible to foresee that it would be the volatility of MBS markets and not some other trigger that would set off the recent turmoil).

4.6 Equity dilution and moral hazard

As a solution to the bailout moral hazard problem, some commentators have suggested imposing on existing shareholders of a troubled bank a very significant dilution of their equity (e.g. though forced issuance of new equity). A dilution should make shareholders more fully internalize the externalities of bank failure and bailout costs. Would such ex-post punishment be able to reduce bank moral hazard as well as our proposed ex-ante Pigouvian tax? The answer is that, not necessarily.

Indeed, observe that the dilution of equity can also be seen as a tax associated with the use of risky wholesale funding. Yet this "recapitalization tax" $\tilde{T}$ is imposed on a bank not in any state of the world as the Pigouvian tax we have suggested, but only conditional on the realization of a negative public signal. Therefore, to obtain an equivalent $\tilde{T}$, the optimal Pigouvian tax T (19) should be scaled by the probability of the taxable event $(1-p)(p-\theta p)$, where the first term is the probability of a negative public signal, and the second term is the probability that the bank has a positive value conditional on that signal – i.e. that the signal is incorrect (when a bank has zero value, any dilution-based tax is zero):

$$\tilde{T} = \frac{T}{(1-p)(p-\theta p)}$$

We can now show that a "recapitalization tax" $\tilde{T}$ prescribed by this formula can exceed X (the highest possible project return), and thus be impossible to implement. Indeed, consider $\tilde{T}$ that would be necessary to align the bank's incentives for $\theta = \theta^*$ and

$s = 1$. Substituting from (7) and (19) it is easy to derive:

$$\tilde{T} = \frac{pX + WR}{L} > X$$

since by (**1**) $pX > L$.

Therefore, when bank incentives to use risky wholesale funding are sufficiently strong it is not possible to align them with the social optimum even with the most severe "recapitalization tax". The intuition for this result is that the banks reaps the benefits of cheap but risky wholesale funding is all states of the world, but is punished only in only some states of the world—when the negative signal is realized. When such states have a low probability, the maximum punishment that can imposed is still not severe enough.

This result may have an interesting link to Hart and Zingales (2009)'s proposal that authorities impose re-capitalization on a bank based on an increase in CDS spreads. Our analysis suggests a possible limitation of that idea: the maximum losses that shareholders can suffer in a dilution are capped by limited liabitlity, and hence may be insufficient to fully align their incentives with the social optimum.

5 Conclusion

Short-term wholesale funding has both benefits and costs. Our paper identifies and analyzes a "dark side" of it – the scope for opportunistic behavior by short-term wholesale financiers (not monitoring banks and abruptly withdrawing funding upon noisy public signals) and by banks (using such risky wholesale funds and assigning them too high creditor seniority).

In a bank cross-section, the model predicts that wholesale funds can be relatively safely used in "traditional" banks that make opaque and non-tradeable relationship loans. In contrast, short-term wholesale funds can create significant risks in "modern" banks that hold arm's length assets with readily available, but noisy, public signals on fundamentals. Examples of such signals include mortgage-backed securities prices, performance of other similar banks, and the health of the housing market. These predictions are consistent with the experiences of the recent credit markets turmoil.

Finally, the paper discusses a number of policy options, including a Pigouvian tax, possibly in the form of a risk-based deposit insurance premium enforced by the FDIC, that reduces banks' incentives to over-use risky short-term wholesale funds.

A Proofs

Lemma 1

1. To see that $d\Pi^B/ds > 0$ consider:

$$\frac{d\Pi^B}{ds} = m^W(1-p)sL(D+W) - \frac{d(C(m^W) - m^W(1-p)sL(D+W))}{ds}$$

   Use (5) to re-arrange:

$$\begin{aligned} \frac{d\Pi^B}{ds} &= m^W(1-p)sL(D+W) - \frac{d(C(m^W) - m^W C'(m^W))}{dm^W}\frac{dm^W}{ds} \\ &= m^W(1-p)sL(D+W) + m^W C''(m^W)\frac{dm^W}{ds} \end{aligned}$$

   Observe that $m^W(1-p)sL(D+W) > 0$. Recall that $C''(m^W) > 0$ and $dm_W/ds > 0$. Therefore both terms are positive and $d\Pi^B/ds > 0$. QED.

2. To see that $d\Pi^B/ds > 0$ consider:

$$\begin{aligned} \frac{d\Pi^B}{dW} &= pX - \frac{d(pWR)}{dW} \\ &= pX - \rho - \frac{d(C(m^W) - m^W(1-p)sL(D+W))}{dW} \end{aligned}$$

   Use (5) to re-arrange:

$$\begin{aligned} \frac{d\Pi^B}{dW} &= pX - \rho - \frac{d(C(m^W) - m^W C'(m^W))}{dm^W}\frac{dm^W}{dW} \\ &= pX - \rho + m^W C''(m^W)\frac{dm^W}{dW} \end{aligned}$$

   Recall that $pX > \rho$. Also recall that $C''(m^W) > 0$ and $dm_W/dW > 0$. Therefore $d\Pi^B/ds > 0$. QED.

Lemma 2 Points 1 and 2 were explained in text. Point 3 requires that m^W and m^W_{Liq} are continuous at s^W. This is easy to verify by applying $[p - \theta p]\, pWR = s^W L(D+W)$ from (12) to m^W (5) and m^W_{Liq}(14). QED.

Proposition 3 We construct an example of parameters under which a bank chooses to assign short-term wholesale financiers creditor seniority $s = 1$ instead of $s = s^W$. This is sufficient to prove existence.

1. Consider a function $C(m)$ which is almost horizontal until the close environ of certain $\bar{m}$, is increasing in that small environ, and is almost vertical after that. This makes the wholesale financiers' choice of monitoring always very close to $\bar{m}$. Such a function allows us to make the effects on seniority on m secondary to the effects of seniority on liquidation decisions and interest rates.

2. We further take:

   - $\bar{m}$ and $C(\bar{m})$ to be both close to 0
   - liquidation value L to be the highest possible: $L = pW$
   - precision of signal θ to be the highest possible: $\theta = \theta^* = 1 - \frac{L}{pX} = 1 - \frac{W}{X}$

3. Under these conditions:

$$
\begin{aligned}
R(s^W) &= \frac{W\rho + C(m^W) - m^W(1-p)sL(D+W)}{Wp} = \frac{\rho}{p} \\
s^W &= \frac{(1-\theta)pW}{L} = \frac{W}{X}\frac{\rho}{p}
\end{aligned}
$$

4. We can substitute everything into the inequality in question:

$$
\begin{aligned}
(1-p)L(D+W)(1-s^W) &> \Delta \\
(1-p)pW(D+W)\left(1 - \frac{W}{X}\frac{\rho}{p}\right) &> p\frac{W}{X}(1-p)\left[D(X-1) + W\left(X - \frac{\rho}{p}\right)\right]
\end{aligned}
$$

5. Arranging terms gives:

$$
\begin{aligned}
X(D+W) &> D(X-1) + WX \\
D &> 0
\end{aligned}
$$

   which always holds. QED.

6. 6. As a side-line, note that the inequality $(1-p)L(D+W)(1-s^W) > \Delta$ does not necessarily hold under milder condition. For example, it does not hold for L close to 0, for θ close to to θ^W (which would make $s^W = 1$).

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Figure 1.

Liquidation and monitoring decisions of wholesale financiers.

Left panel: **Without a noisy signal** *Right panel:* **With a noisy signal**