WAREHOUSE BANKING*

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Abstract

This paper develops a theory of banking rooted in the evolution of banks from warehouses of commodities and precious goods, which occurred even before the invention of coinage or fiat money. The theory helps to explain why modern banks offer warehousing (custodial and deposit-taking) services within the same institutions that provides lending services and how banks create *funding liquidity* by creating private money. In our model, the warehouse endogenously becomes a bank because its superior storage technology allows it to enforce loan repayment most effectively. The warehouse makes loans by issuing "fake" warehouse receipts—those not backed by actual deposits—rather than by lending out deposited goods. The model provides a rationale for banks that take deposits, make loans, and have circulating liabilities, even in an environment without risk or asymmetric information. Our analysis provides new perspectives on narrow banking, liquidity ratios and reserve requirements, capital regulation, and monetary policy.

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> The banks in their lending business are not only not limited by their own capital; they are not, at least immediately, limited by any capital whatever; by concentrating in their hands almost all payments, they themselves create the money required....
>
> Wicksell (1907)

1 Introduction

Motivation and research questions. Banking is an old business. The invention of banking preceded the invention of coinage by several thousand years.[1] Banks evolved from ancient warehouses, where cattle, grain, and precious metals were deposited for storage.[2] For example, in ancient Egypt, grain harvests were "deposited" (or stored) in centralized warehouses and depositors could write orders for the withdrawal of grain as means of payment. These orders constituted some of the earliest paper money. Later, London's goldsmiths operated a similar payment system, backed by the "money or plate" that they held in their safes.[3] Eventually these warehouses for the safe storage of commodities began making loans, thereby evolving into banks. By extending credit, these institutions transformed from simple warehouses of liquidity to creators of liquidity. To this day, the same institutions that provide safekeeping services also engage in the bulk of lending in the economy and are thereby responsible for significant liquidity creation (see, e.g., Berger and Bouwman (2009)). Modern commercial and retail banks keep deposit accounts, provide payment services and act as custodians as well as make corporate and consumer loans.

[1]The earliest known coins were minted in the kingdom of Lydia in the 7th Century BC (British Museum (2016)). Banking is much older. It seems to have originated in ancient Mesopotamia c. 3000 BC. Early laws pertaining to banks (banking regulation) appeared in the Code of Hammurabi and the Laws of Eshnunna (Davies (1994), Geva (2011)).

[2]The connection between banking and warehousing is fundamental. Throughout history, banks have evolved systematically from warehouses, specifically from warehouses whose deposit receipts served as private money. For example, depositories of barely and silver evolved into banks in ancient Mesopotamia (Geva (2011)); grain silos developed into banks in ancient Egypt (Westermann (1930)); goldsmith bankers came to be in Early Modern Europe due to their superior safes for storing "money and plate in trust" (Richards (1934) p. 35, Lawson (1855)); rice storage facilities began the practice of fractional reserve banking in 17th century Japan (Crawcour (1961)); tobacco warehouses were instrumental in the creation of banking and payments in 18th century Virginia, where warehouse receipts were ultimately made legal tender (Davies (1994)); still in the 19th century, granaries were doing banking in Chicago (Williams (1986)); and even today grain silos in Brazil perform banking activities (Skrastins (2015)).

[3]These goldsmiths owned safes that gave them an advantage in safe-keeping. This interpretation is emphasized in He, Huang and Wright (2005, 2008) as well in many historical accounts of banking, including, for example, the Encyclopedia Britannica, which states that "The direct ancestors of modern banks were the goldsmiths. At first the goldsmiths accepted deposits merely for safe keeping; but early in the 17th century their deposit receipts were circulating in place of money" (1954, vol. 3, p. 41).

Historically, why did banks start out as warehouses? And, even today, why do banks offer deposit-taking, account-keeping, payment, and custodial services—namely, warehousing services—within the same institution that provides lending services? How do banks that combine warehousing and lending services create liquidity? And how does banks' creation of private money contribute to this liquidity creation? Finally, what does a theory of banking that addresses these questions have to say about contemporary regulatory initiatives like bank capital and liquidity requirements and proposals like narrow banking?

Our Theory. In this paper, we address these questions by developing a theory of banking based on the warehousing function of the bank. In our model, the institutions that provide the warehousing services endogenously perform the lending in the economy. The model relies on two key assumptions. First, warehouses have an efficient storage technology.[4] For example, warehouses may prevent spoilage as grain silos did in ancient Egypt or may protect against theft as goldsmiths' safes did in Early Modern Europe.[5] Second, no firm's output is pledgeable,[6] so a debt contract written on a firm's future cash flow is not readily enforceable. This impedes a firm's access to credit. But warehouses use their superior storage technology to circumvent this problem. The reason is as follows. A firm wants to deposit its output in a warehouse to take advantage of the warehouse's efficient storage technology. However, once a firm deposits with the warehouse, the deposit can then be seized by the warehouse. Hence, as long as the benefits of warehouse storage (relative to private storage) are high enough, it is incentive compatible for a firm that borrows from a warehouse to repay its debt in order to access the warehouse's storage services. This mechanism explains why the same institutions should provide both the warehousing and lending services in the economy.[7]

This mechanism relies on the firm depositing its output in the same warehouse that gave it a loan. However, a firm could also deposit in a different warehouse. Could it thus make use of the second warehouse's storage technology and avoid repaying its debt to the first warehouse? Not as long as there is an an interbank, or "inter-warehouse," market for loans. This is because the second warehouse can buy the firm's debt from the first warehouse and subsequently seize the firm's deposits. As a result, the firm ends up repaying in full no matter which warehouse it deposits in. The interbank

[4] Allen and Gale (1998) also assume that the storage technology available to banks is strictly more productive than the storage technology available to consumers.

[5] For a model that examines monetary exchange and credit in an environment that has theft, see Sanches and Williamson (2010).

[6] See Holmström and Tirole (2011) for a list of "...several reasons why this [non-pledgeability] is by and large reality" (p. 3).

[7] Empirical evidence that seems to support this result appears in Skrastins (2015). Using a differences-in-differences research design, Skrastins (2015) documents that agricultural lenders in Brazil extend more credit when they merge with grain silos, i.e. banks lend more when they are also warehouses.

market allows warehouses to enforce repayment in the presence of multiple lenders. Successful competitive banking systems throughout history, such as those operated by Egyptian granaries and London goldsmiths as well as those in existence today, have indeed developed interbank clearing arrangements, consistent with our theory.[8]

Our result that interbank clearing prevents the borrower from being able to renege on his debt and deposit elsewhere means that long-term bilateral agreements are upheld even though contracts in our model are non-exclusive. This suggests that well-functioning secondary markets may mitigate some of the inefficiencies associated with non-exclusive contracting.[9]

Our model of warehouse banking leads to a new perspective on banks' liquidity creation. In our model, the receipts that warehouses issue for deposits circulate as a medium of exchange—they constitute private money. This is the first step in the bank's creation of *funding liquidity*, which we define as the initial liquidity that is used to fund productive investments.[10] The second step in the liquidity creation process—and the key reason that banks increase aggregate funding liquidity—is that they make loans in warehouse receipts rather than in deposited goods. When warehouses make loans, they issue new receipts that are not backed by any new deposits. Due to their the lack of deposit-backing, we sometimes refer to these new receipts as "fake receipts," although we emphasize that they are good-value IOUs. These fake receipts provide firms with working capital, allowing them to make more productive investments. Thus, when a warehouse-bank makes a loan, it is not reallocating assets—from cash holdings into lending—on the left-hand side of its balance sheet. Rather, because it is lending by issuing new receipts, it is creating a new liability. Making a loan thus expands both sides of the balance sheet. This is depicted in Figure 1.[11]

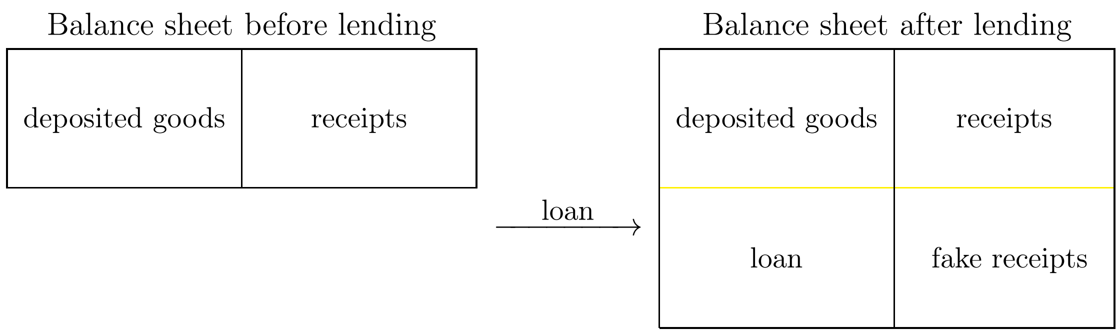
[8]See Geva (2011) p. 141 for a description of how warehouse-banks in Greco-Roman Egypt relied on inter-granary transfers that were entirely account-based. See Quinn (1997) and Geva (2011) for analyses of interbank clearing arrangements between London goldsmiths.

[9]Papers on the inefficiencies of non-exclusive contracting in credit markets include Attar, Casamatta, Chassagnon and Décamps (2015), and Parlour and Rajan (2001). Attar, Mariotti and Salanié (2011) show that non-exclusivity can cause market breakdowns in markets with adverse selection such as insurance.

[10]Our use of the term "funding liquidity" is somewhat similar to that of Brunnermeier and Pedersen (2009). They define it as the availability of funding for traders. In our case, it is related to the availability of funds to entrepreneurs for investment in capital and labor, and we have a definition of *how much* funding liquidity is created that is novel. See also Holmström and Tirole (1998) where the focus is on funding liquidity, but from the perspective of credit-constrained entrepreneurs and the role of the government.

[11]A related expansion of bank balance sheets occurs in the textbook relending model of bank money creation—the so called "money multiplier" associated with fractional reserves banking (see, e.g., Samuelson (1980), ch. 16). In this model, a bank takes deposits and lends them out. Then, later, the deposits are deposited back in the bank, expanding the balance sheet. That is the money multiplier is created when the bank keeps only a fraction of its deposits on reserve, lending out the rest. By contrast, warehouse-banks in our model make loans even with *no* deposited goods, and this expansion of economic activity occurs with a single transaction—a loan. Borrowers use warehouse receipts as working capital to make productive investments. As a result, what may seem like a zero-net transaction—making a loan by issuing new receipts—creates an *intertemporal* transfer of liquidity, improving efficiency.

Figure 1: The warehouse's balance sheet expands when it makes a loan, creating liquidity.



The reason that fake warehouse receipts are valuable to firms is that they cannot pay their suppliers or laborers on credit, due to the non-pledgeability of their output. However, they can circumvent this problem by borrowing from a warehouse. Warehouse deposits do not suffer from the non-pledgeability problem, so their receipts are readily accepted as payment; in an extension we show how this property of receipts can be sustained even when the warehouse itself has a pledgeability problem. Thus, when a warehouse extends credit by issuing new receipts, it creates liquidity for borrowers. In other words, liquidity is created on the asset side, not the deposit side, of the warehouse's balance sheet. When a warehouse makes a loan, it creates both an illiquid asset, the loan, and a liquid liability, the receipt. This is liquidity transformation, one of the fundamental economic roles of banks. Our model suggests, however, that liquidity transformation occurs only when banks make loans. The usual process in which banks first receive deposits of cash, issue liquid (demandable) claims against them to depositors, and then make illiquid loans is turned on its head. The lending that creates liquidity occurs *before* cash is deposited in the bank.

The issuance of new liabilities to make loans is a realistic feature of our model, even in the context of modern banks. When a bank makes a loan today, it does not transfer physical currency to the borrower, but it rather creates a deposit in the borrower's name. In other words, a bank loan is an exchange of IOUs: the borrower gives the bank a promise to repay later (the loan) and in exchange the bank gives the borrower a promise to repay later (the deposit). Our model explains how these exchanges of IOUs can create funding liquidity by providing working capital for firms, thereby illuminating why banks lend in private money as opposed to in currency. Our approach in which bank lending creates deposits is reminiscent of Hahn (1920):[12]

[12] See also Werner (2014) and the "goldsmith anecdote" in Greenbaum, Thakor and Boot (2015).

> We thus maintain—contrary to the entire literature on banking and credit—that the primary business of banks is not the liability business, especially the deposit business, but in general and in each and every case an asset transaction of a bank must have previously taken place, in order to allow the possibility of a liability business and to cause it. The liability business of banks is nothing but a reflex of prior credit extension.... (Hahn, 1920, p. 29)

Keynes makes a related point:

> It is not unnatural to think of deposits of a bank as being created by the public through the deposits of cash representing either savings or amounts which are not for the time being required to meet expenditures. But the bulk of the deposits arise out of the action of the banks themselves, for by granting loans, allowing money to be drawn on an overdraft or purchasing securities, a bank creates a credit in its books which is the equivalent of a deposit. (Keynes in his contribution to the Macmillan Committee, 1931, p. 34)

Quinn and Roberds (2014) show empirically that this ability of banks to originate loans in private money has important real consequences. They exploit a 17th century policy change that allowed the Bank of Amsterdam to create unbacked private money. They show that this helped the Bank finance its loans and, further, resulted in the Bank florin becoming the dominant international currency throughout Europe.

Application to modern banks. Despite its link to the origins of banking, our model applies to modern banks as well. As in our model, savings and payments services are two of the key services that *modern* banks provide. Instead of providing safekeeping for grain or gold and issuing receipts that serve as a means of payment, modern banks create bank accounts for storing wealth and issue claims, checkbooks, and cards that serve as means of payment. In the model, loan repayment is ensured by the threat of excluding a delinquent borrower from warehousing services. In other words, the institutions that control savings and payments—the warehouses—are the natural banks in the economy.

The incentive effect of the exclusion threat arises from warehouse storage being more efficient than private storage. Historically, granaries and goldsmiths benefited from technological advantages and returns to scale for storing real goods. Today, banks benefit from similar advantages for storing money. The costs of private storage of money are reflected in the negative bond yields that currently prevail in Japan, Switzerland, and around the Eurozone. Further, in 2011, even before sovereign rates became negative, the Bank of New York–Mellon, which is the largest depository institution in the world today, charged its depositors a fee to hold cash (Rappaport (2011)). This bank is usually classified as a custodian bank, i.e. an institution responsible for the safeguarding, or *warehousing*, of financial assets. Its negative deposit rates for cash reflected its own storage cost.

Recently, exclusion from the banking system made the high costs of private cash storage salient for some firms in Colorado. Specifically, marijuana businesses have had their bank accounts closed, forcing them to store cash privately.[13] The costs of private storage are reflected in the following quote from the *New York Times*

> [Marijuana entrepreneur] Dylan Donaldson...knows the hidden costs of a bank-challenged business. He has nine 1,000-pound safes bolted to the floor in...his dispensary [and] he pays $100,000 a year for armed guards (Richtel (2015)).

Policy implications for contemporary banking. Our warehousing view of banking provides some new insights into financial regulatory policy. One proposal is narrow banking. We interpret a narrow bank as an institution that can invest its deposits in only "safe" assets, namely in cash or marketable liquid securities such as sovereign bonds (see Kay (2010), for example). The proposal forces the separation of the warehousing and lending functions of banks. Our analysis suggests that banks create liquidity only when they perform this dual function, implying that narrow banks create no liquidity. Less extreme proposals, such as the liquidity (reserve) ratio in Basel III, demand that banks invest at least a specified fraction of their assets in cash and marketable liquid securities. These too stifle banks' liquidity creation, since they impede banks' issuance of new receipts to expand the supply of liquidity.

We also include an extension to examine the effect of bank capital (equity). The effect of increasing bank capital contrasts with the effect of increasing bank liquidity. Increasing bank capital actually *enhances* banks' ability to create funding liquidity by reducing non-pledgeability problems between banks and depositors, making warehousing relatively more efficient.

We extend the model to include a central bank and argue that a higher policy rate does not always lead to lower liquidity creation. We establish conditions under which such a policy can actually *encourage* lending by warehouse-banks. In other words, "tighter" monetary policy can loosen credit in some circumstances.

Related literature. Among other issues, our paper addresses questions related to the *raison d'etre* of banks, the identity of bankers, and the role of circulating bank liabilities. A paper that also addresses these questions is Gu, Mattesini, Monnet and Wright (2013). They show that players who have greater ability to commit to repay depositors endogenously emerge as banks, in the sense that they make delegated investments and their liabilities circulate to facilitate payments among other players. In our model, we

[13]The accounts were closed because, although marijuana is legal in Colorado, it is considered illegal by the federal government. As a result, traditional banks closed the accounts of marijuana businesses, fearing prosecution for aiding and abetting illegal drug dealers (Richtel (2015)).

go one step further by asking not only who should make delegated investments, but also who should make loans. In our model, a bank is an intermediary between a depositor and a borrower, not only between a depositor and an investment technology. Unlike in Gu, Mattesini, Monnet and Wright (2013), our focus is mainly on the ability of banks to enforce contracts with borrowers, rather than on their ability to commit to repay depositors (except in the extension in Subsection 5.2, which is all about banks' limited commitment in connection with bank capital). Consequently, we address a host of issues that are not the focus of their analysis.

Gu, Mattesini, Monnet and Wright (2013) take a *mechanism design* approach to explain why banks exist. In other words, they show that banks are necessary to implement the best incentive-feasible allocation. We apply this approach to our environment in Subsection 5.4. There, we show that if warehouses act as banks and they can trade loans in an interbank market, then warehouse-banking implements the best incentive-feasible allocation. Thereby, we provide a rationale for banks and markets together.

Another paper that emphasizes the circulation of bank liabilities is Kiyotaki and Moore (2001). In that paper, someone with verifiable collateral (specifically, a "Scottish laird...[who's] castle is publicly visible" (p. 22)) becomes a banker. This is because his collateral guarantees his liabilities, allowing them to circulate freely. Thus, Kiyotaki and Moore emphasize banks' advantage in taking deposits and creating private money, but, unlike us, do not analyze banks' advantage in enforcing loan repayment.

Our paper is also related to the literature on limited enforcement in financial contracting in which repayment is enforced by the threat of exclusion from markets. For example, Bolton and Scharfstein (1990) show that the threat of exclusion from credit markets can mitigate incentive problems in corporate finance: if investors can commit to cut off future credit from an underperforming firm, the firm's manager has incentive to exert effort. Bulow and Rogoff (1989) analyze how the threat of exclusion can mitigate incentive problems in sovereign debt markets. They show that this threat to cut off future credit is not sufficient to sustain borrowing in equilibrium—exclusion from efficient savings is also needed.[14] They show, however, that exclusion from savings is not implementable without a formal commitment mechanism, even in an infinite horizon setting. Their point that exclusion from savings is essential to sustain borrowing supports our view that warehouses—the institutions that controlled the savings technologies historically—are the natural banks. However, in our model exclusion from savings *is implementable*, even in a finite-horizon setting.[15]

[14] Efficient savings in Bulow and Rogoff (1989) constitutes insuring future consumption risk. Specifically, access to markets plays two roles. It allows countries to smooth consumption over time (borrowing) and across future states (savings). Exclusion from both of these roles is necessary to support borrowing.

[15] Bond and Krishnamurthy (2004) study the problem of credit market exclusion with competing banks. They find that in this setting a regulatory intervention is required to implement exclusion. They do not have an interbank market. In our model the interbank market facilitates the enforcing of borrower repayment,

Our result that the the presence of an interbank market can mitigate repayment frictions resembles Broner, Martin and Ventura's (2010) finding that secondary markets for sovereign debt reduce strategic default. In that model, a sovereign may default if its debt is held by foreign investors, but these foreign investors are still willing to lend to the sovereign because they anticipate being able to sell their debt to domestic investors. In other words, the secondary market reduces a borrower's incentive to default. In our model, in contrast, the interbank market increases a creditor' ability to enforce repayment.

In our model, warehouses endogenously function as financial intermediaries. In contrast to most of the contemporary literature explaining why banks exist, there is no asymmetric information or risk in our model—the warehouses' function as intermediaries results entirely from their superior storage technology.[16] Specifically, they have *no* superior ability to screen or to monitor loans in an environment of asymmetric information, as in Diamond (1984) and Ramakrishnan and Thakor (1984). Further, because we assume that all agents are risk neutral, banks also do not provide better risk sharing for risk-averse depositors as in Bryant (1980) and Diamond and Dybvig (1983). Technological and financial developments have diminished informational frictions and provided alternatives to banks for risk-sharing (see the discussion in Coval and Thakor (2005)). This should have led to a decline in financial intermediaries' share of output (and corporate profits) in developed economies, but their financial sectors have continued to grow. This suggests that other forces also determine the demand for banking services; we suggest that warehousing-type financial services may be one important determinant, one linked with the very origins of banking. Further, in less developed markets, lending services are linked with storage services for commodities.[17]

Our paper is also related to the literature in which bank liquidity creation is linked to the provision of consumption insurance. Important contributions include Allen and Gale (1998), Allen, Carletti and Gale (2014), Bryant (1980), Diamond and Dybvig (1983), and Postlewaite and Vives (1987). We view our paper as offering a view of bank liquidity creation that *complements* the consumption insurance view in the existing literature, a view that has provided deep insights into a variety of phenomena like bank runs and deposit insurance (Bryant (1980) and Diamond and Dybvig (1983)), financial crises (e.g. Allen and Gale (1998)), and the role of financial intermediaries *vis-à-vis* markets (e.g. Allen and Gale (2004)). Juxtaposing our analysis with the existing literature, liquidity creation is seen to have two important dimensions: consumption insurance for depositors/savers and elevated funding liquidity for

thereby obviating the need for regulation.

[16]Thus, the contract between the bank and its depositors does not confront an incentive problem that needs to be solved by contract design as, for example, in Calomiris and Kahn (1991).

[17]For example, see Skrastins (2015).

entrepreneurs/borrowers. These mutually-reinforcing views of bank liquidity creation are consistent with the idea that banks create liquidity by both taking in deposits and selling loan commitments (e.g. Kashyap, Rajan and Stein (2002)).[18]

Two recent papers that emphasize that banks create money (or deposits) when they lend are Bianchi and Bigio (2015) and Jakab and Kumhof (2015). An incremental contribution of the paper relative to Bianchi and Bigio (2015) is that we provide a microfoundation for why warehouse receipts (bank deposits), and not real goods, are used as a means of payment, and an incremental contribution relative to Jakab and Kumhof (2015) is that we explain why banks' lending by creating deposits increases aggregate output without assuming that money is a direct input in the production function.

Brunnermeier and Sannikov (2016) also model the role of financial intermediaries in money creation. Like us, they argue that banks create value by selling liquid claims (deposits) and buying illiquid claims (loans), even without transferring wealth from borrowers to savers. Unlike us, they focus on the role that risk transformation plays in banks' creating money as a store of value. In contrast, we focus on the role that banks play in creating money as a medium of exchange; in fact, there is no risk in our model.

Layout. The rest of the paper is organized as follows. Section 2 provides an example in a simplified set-up in which all the key forces of the model are at work. Section 3 develops the formal model. Section 4 solves two benchmark models: (i) the first-best allocation and (ii) one in which warehouses cannot issue fake receipts. It provides the solution of the model, and also contains the main results pertaining to an analysis of liquidity creation and fractional reserves. Section 5 considers the welfare implications of four policies: liquidity requirements, narrow banking, capital requirements, and monetary policy. In that section we also analyze our environment from the point of view of mechanism design. There, we show that the markets we consider implement the constrained efficient outcome. In Section 6, we show that our conclusions are robust to different utility specifications and to the possibility of bank runs. Section 7 is the Conclusion. The appendix contains a formal analysis of the interbank market as well as all proofs and a glossary of notation.

2 Motivating Example

In this section we provide a numerical example that illustrates the main mechanism at work in a simplified setup. For most of the example, we simplify the model to include just one farmer, one laborer, and one warehouse, although we also discuss the case

[18]Our paper is also related to papers in which debt serves as inside money. For example, Kahn and Roberds (2007) develop a model that shows the advantage of circulating liabilities (transferable debt) over simple chains of credit. Townsend and Wallace (1987) develop a model of pure intertemporal exchange with informationally-separated markets to explain the role of circulating liabilities in exchange.

in which there are two warehouses and show that the analysis holds with competition among warehouses. We examine a sequence of increasingly rich cases to demonstrate the efficiency gains from warehousing and from issuing fake receipts. Specifically, we consider: (i) the case without a warehouse, (ii) the case in which a warehouse provides only safe-keeping services but does not lend, (iii) the case in which a warehouse provides both safe-keeping and lending services, (iv) the case in which there are two competing warehouses that provide these safe-keeping and lending services, and (v) the first-best case, in which the allocation is efficient.

The example shows that, even without lending, warehousing alone increases efficiency due to more efficient storage. But when a warehouse can issue fake receipts, it does more to improve efficiency—it creates liquidity that the farmer invests productively. This efficiency gain is allocational and is more important than the simple storage efficiency gain because it involves *other players* in the economy investing in more efficient technologies. Finally, the analysis of the first-best allocation suggests that there is an efficiency loss in the second best in that even when the warehouse can issue fake receipts, it still creates less liquidity than in the first-best.

The setup is as follows. There are three dates: Date 0, Date 1, and Date 2. The farmer has an endowment e of twelve units of grain at Date 0 and no one else has any grain. At Date 0 the farmer can borrow B from the warehouse at gross rate one. We assume that warehouse deposit rates and wages w are also all set equal to one.[19] The farmer produces over the period from Date 0 to Date 1 and he stores his output over the period from Date 1 to Date 2. If the farmer stores his grain privately, it depreciates at rate δ, and we set $\delta = 20\%$. If he stores it in a warehouse, it does not depreciate. Suppose there is no discounting, so workers are willing to store grain in warehouses at the deposit rate of one. The farmer's production technology transforms a unit of labor and a unit of grain at Date 0 into four units of grain at Date 1 with constant returns. In other words, the farmer has a Leontief production function in the first period that takes grain investment i, which we will refer to as "capital investment," and labor ℓ and produces output $y = 4 \min\{i, \ell\}$ at Date 1. We assume that this output is not pledgeable; however, a warehouse can seize the deposits it holds. Everyone consumes only at Date 2.

The parameter values are summarized in Figure 2 and the timing is illustrated in Figure 3.

[19]These prices—i.e. rates and wages—result from competition in the full model, leaving rents to the farmer. We take them as given in this example for simplicity.

Figure 2: Summary of notation and values in example in Section 2.

Quantity	Notation	Value in Example
Farmer's endowment	e	12
Farmer's technology	y	$4 \min\{i, \ell\}$
Depreciation rate	δ	20%
Wage	w	1

Figure 3: A Simplified Timeline Representation of the Sequence of Moves

Date 0

- the farmer has endowment e and borrows B from the warehouse
  he invests i in grain, and $w\ell$ in labor
- the laborer exerts labor ℓ and deposits his wages $w\ell$ in the warehouse

Date 1

- the farmer produces y
  he either repays and deposits or diverts and stores privately
  warehouses trade in interbank market (in case (iv))

Date 2

- the farmer, laborer, and warehouse consume

Definition of liquidity: We refer to the farmer's expenditure on capital and labor $i + w\ell$ as the "total investment." We measure liquidity by the ratio Λ of the farmer's total investment to his initial endowment, which we refer to as the *liquidity multiplier*,

$$\Lambda = \frac{i + w\ell}{e}.$$

To see this definition clearly, observe that if the farmer invests only his endowment in production, the liquidity multiplier is one. If the liquidity multiplier is greater than one, that indicates that he has obtained credit (or *outside liquidity* in the sense of Holmström and Tirole (2011)) to scale up his investment. Further, since the farmer has the entire initial grain endowment (no one else has any grain in the model), this measure of outside liquidity is also a measure of total funding liquidity in the model.

(i) No warehousing. Consider first the case in which there is no warehousing. Thus, the farmer must pay the laborer in grain. To maximize his Date 2 consumption, the farmer maximizes his Date 1 output and then stores his output from Date 1 to Date 2. Given that he cannot borrow, his budget constraint reads $i + w\ell = 12$. To maximize his Date 1 output, he invests in equal amounts of capital i and labor ℓ (as a result of the Leontief technology). Since his endowment is twelve and wages are one, he sets $i = \ell = 6$ and produces $y = 4 \times 6 = 24$ units of grain. He then stores his grain privately from Date 1 to Date 2 and this grain depreciates by twenty percent; the farmer's final payoff is $(1 - 20\%) \times 24 = 19.2$ units. $\Lambda_{\text{nw}} = 1$, so there is no liquidity creation.

(ii) Warehousing but no fake receipts. Now consider the case where there is a warehouse, but that it performs only the function of safekeeping. When a depositor (the farmer or the laborer) deposits grain in the warehouse, the warehouse issues receipts and holds the grain until it is withdrawn. In this case, the farmer again maximizes his Date 1 output in order to maximize his Date 2 consumption. Again, he will invest equal amounts of capital and labor. He cannot borrow from the warehouse, so he again just divides his endowment fifty-fifty between capital investment and labor, setting $i = \ell = 6$ and producing $y = 4 \times 6 = 24$ units of grain. He now stores his grain in the warehouse from Date 1 to Date 2. Since it is warehoused, the grain does not depreciate; the farmer's final payoff is 24 units. Warehousing has added 4.8 units to the farmer's consumption by increasing efficiency in storage. But the warehouse has not created any liquidity for the farmer since the initial investment in the technology $i + w\ell = e = 12$ is the same as in the case in which there is no warehouse. There is no liquidity creation, $\Lambda_{\text{nr}} = 1$.

(iii) Warehousing with fake receipts. Now consider the case in which there is a warehouse that can not only provide safe-keeping but can also issue fake receipts to make loans. Since the farmer's technology is highly productive, he wishes to borrow to scale it up. But the farmer already holds all twelve units of grain in the economy, so how can he scale up his production even further? The key is that the farmer can borrow from the warehouse in warehouse receipts. Observe that the receipts the warehouse uses to make loans are *not* backed by grain; they are "fake receipts." However, if the laborer accepts payment from the farmer in these fake receipts, they are still valuable to the farmer—they provide him with "working capital" to pay the laborer.

The farmer again sets his capital investment equal to his labor investment, $i = \ell$. Given that he can borrow B in receipts from the warehouse, however, he can now invest a total up to $i + w\ell = e + B$. Thus, recalling that wages w are one, his optimal investment is

$$i = \frac{e+B}{2} = 6 + \frac{B}{2} \tag{1}$$

and the corresponding Date 1 output is

$$y = 4i = 24 + 2B. \tag{2}$$

Given that this technology is highly productive and has constant returns to scale, the farmer wishes to expand production as much as possible. The amount he can borrow from the warehouse, however, is limited by the amount that he can credibly promise to repay. Since we have assumed that the farmer's output is not pledgeable, his creditor (i.e., the warehouse) cannot enforce the repayment of his debt. However, if the farmer deposits in the warehouse, it is possible for the warehouse to seize the deposit. Thus, after the farmer produces, he faces a tradeoff between not depositing and depositing. If he does not deposit, he stores privately, so his grain depreciates, but he avoids repayment. If he does deposit, he avoids depreciation, but the warehouse can seize his deposit and force repayment. The warehouse lends to the farmer only if repayment is incentive compatible. For the repayment to be incentive compatible, the farmer must prefer to deposit in the warehouse and repay his debt rather than to store the grain privately and default on his debt. This is the case if the following incentive compatibility constraint holds

$$y - B \geq (1 - 20\%)y. \tag{3}$$

The maximum the farmer can borrow B is thus given by

$$\big(24 + 2B\big) - B = \big(1 - 20\%\big)\big(24 + 2B\big), \tag{4}$$

or $B = 8$. This corresponds to $i = \ell = 10$.

Observe the endogenous emergence of intermediation. The warehouse lends to the farmer in fake receipts. The farmer then transfers these fake receipts to the laborer. Thus, the laborer has a claim on the warehouse and the warehouse has a claim on the farmer, who has made a productive investment. This is a canonical *banking* arrangement because: (i) the warehouse is both debtor to the laborer and creditor to the farmer, and (ii) the warehouse's liabilities circulate as a means of payment. In this environment, the warehouse endogenously becomes the bank. This result relies only on the warehouse having a superior storage technology.

With warehousing and fake-receipts, the liquidity creation is given by

$$\Lambda = \frac{i + w\ell}{e} = \frac{10 + 10}{12} = \frac{5}{3}. \tag{5}$$

The farmer is able to scale up his production only when the warehouse makes loans by writing fake receipts. Hence, liquidity is created on the asset side, not the deposit side, of the warehouse's balance sheet, as discussed in the introduction.

If the farmer could pay the laborer on credit, he would not need to borrow from the warehouse and he could expand production even further. However, an impediment to this is that the laborer cannot enforce repayment from the farmer (because the output is not pledgeable and the laborer has no way to seize it). Therefore, the farmer's promise to the laborer is not credible.

(iv) Competing warehouses. Now consider the case in which there are two warehouses, each of which can provide safe-keeping and issue fake receipts to make loans. We refer to these warehouses as Warehouse 0 and Warehouse 1. In this case, the farmer's borrowing and investment problems are the same as they are in the case of warehousing with fake receipts above. The farmer borrows an amount B from one warehouse, say Warehouse 0, in fake receipts, which he uses to pay the laborer. The expressions for his investment and output as a function of B are exactly as in equations (1) and (2) above. However, the amount the farmer can promise to repay Warehouse 0 is now limited by an additional constraint: at Date 1, he must prefer to deposit and repay Warehouse 0 not only to diverting and storing privately, but also to diverting and storing with Warehouse 1. This additional constraint may inhibit the amount B that Warehouse 0 is willing to lend to the farmer at Date 0.

We now calculate the farmer's value of depositing in Warehouse 1. Suppose the farmer deposits his output $y = 24 + 2B$ in Warehouse 1. In this case, Warehouse 0 holds the farmer's promise to repay B units of grain, but does not hold the farmer's grain. Thus, he cannot enforce the repayment by seizure. Warehouse 0's private value for the farmer's debt is zero. In contrast, Warehouse 1 holds the y units of the farmer's grain, and thus could enforce repayment, if it held the farmer's debt. Warehouse 1's value for the farmer's debt is thus B. Warehouse 0 and Warehouse 1 have a profitable trade: Warehouse 0 sells the farmer's debt to Warehouse 1 for *any* positive price less than B. Warehouse 1 can then seize the grain B that the farmer owes. As a result, the farmer's repayment if he deposits in Warehouse 1 coincides with his repayment if he deposits in Warehouse 0.

Since the farmer's repayment does not depend on the warehouse in which he deposits, he always weakly prefers to deposit in the warehouse that granted him the original loan. The presence of a competing warehouse does not affect the farmer's incentive constraint. He repays his debt as long as repayment and warehouse storage is preferable to diversion and private storage, as expressed in the incentive constraint (3).

(v) First best. We now consider the first best allocation of resources, i.e. the output-maximizing allocation subject only to the aggregate resource constraint and without the incentive constraint due to the pledgeability friction. We do this in order to emphasize that the incentive compatibility constraint limits liquidity creation. In the first-best allocation, the farmer invests his entire endowment in capital $i = e = 12$ and laborers exert equal labor $\ell = 12$. In this allocation, output $y = 4i = 48$ and liquidity creation is given by

$$\Lambda_{\text{fb}} = \frac{i + w\ell}{e} = \frac{12 + 12}{12} = 2. \tag{6}$$

We see therefore that, in the second best, allowing warehouses to make loans in fake receipts moves the economy closer to the first best level, but does not achieve it.

Figure 4: Summary of liquidity creation the example in Section 2.

Case	Date-1 Output y	Date-2 Output	Liquidity Λ
No warehouses	24	19.2	1
Warehouses without lending	24	24	1
Warehouses with lending	40	40	5/3
First-best	48	48	2

3 Model

In this section we describe the baseline model. We also specify the maximization programs of the different agents.

3.1 Timeline, Production Technology and Warehouses

There are three dates, Date 0, Date 1, and Date 2 and three groups of players, farmers, warehouses, and laborers. There is a unit continuum of each type of player. There is one real good, called grain, which serves as the numeraire. There are also receipts issued by warehouses, which entail the right to withdraw grain from a warehouse.

All players are risk neutral and consume only at Date 2. Denote farmers' consumption by c^f, laborers' consumption by c^l, and warehouses' consumption by c^b (the index b stands for "bank"). Farmers begin life with an endowment e of grain. No other player has a grain endowment. Laborers have labor at Date 0. They can provide labor ℓ at the constant marginal cost of one. So their utility is $c^l - \ell$. Farmers have access to the following technology. At Date 0, a farmer invests i units of grain and ℓ units of labor. At Date 1, this investment yields

$$y = A \min\{\alpha i, \ell\}, \tag{7}$$

i.e. the production function is Leontief.[20] The output y is *not pledgeable*. At Date 1 farmers have no special production technology: they can either store grain privately or store it in a warehouse.

If grain is not invested in the technology, it is either stored privately or stored in a warehouse. If the grain is stored privately (by either farmers or laborers), it depreciates at rate $\delta \in [0, 1)$. If player j stores s_t^j units of grain privately from Date t to Date $t+1$, he has $(1-\delta)s_t^j$ units of grain at Date $t+1$. If grain is stored in a warehouse, it does not depreciate. Further, if grain is stored in the warehouse, the warehouse can seize it.

The assumption that the warehouse can store grain more efficiently than the individual farmer has a natural interpretation in the context of the original warehouses from which banks evolved. These ancient warehouses tended to be (protected) temples or the treasuries of sovereigns, so they had more power than ordinary individuals and a natural advantage in safeguarding valuables.[21] In more recent times, warehouses tended to be the safes of goldsmiths, so they had a physical advantage in safeguarding valuables. Note that physical safes play an important role in banking today, even in developed economies. For example, custodians like Clearstream hold physical certificates for all publicly-listed companies in Germany. Our assumption on δ can thus be viewed either as a technological advantage arising from specialization acquired through (previous) investment and experience or as a consequence of the power associated with the warehouse.[22]

When players store grain in warehouses, warehouses issue receipts as "proof" of these deposits. All receipts are payable to the "bearer upon demand," so the bearers of receipts can trade them among themselves. Warehouses can issue "proof-of-deposits" receipts even when there is no deposit. These receipts, which we refer to as "fake receipts," still entail the right to withdraw grain from a warehouse, and thus they are warehouses' liabilities that are not backed by the grain they hold. Receipts backed by grain are indistinguishable from fake receipts.

The markets for labor, warehouse deposits, and loans are competitive.

[20] None of our main results depend on the functional form of the production function. For example, if labor were the only input to the farmers' production function all the results would go through.

[21] Thus, whereas our focus is on private money (fake receipts), the alternative, sovereign-power-linked interpretation of the storage advantage of the warehouse over individuals means that our model may complement the chartalist view of money creation by the state (e.g. Knapp (1924) and Minsky (2008)). We thank Charles Goodhart for this interpretation.

[22] This power was important for several reasons that complement our approach and provide alternative interpretations of the deep parameters in the model. First, it enabled grain, gold, or other valuable commodities to be stored safely, without fear of robbery. Second, power enabled the creditor to impose greater penalties on defaulting borrowers. Third, power also generated a greater likelihood of continuation of the warehouse, and hence of engaging in a repeated game with depositors. This created reputational incentives for the warehouse not to abscond with deposits.

3.2 Financial Contracts

There are three types of contracts in the economy: labor contracts, deposit contracts, and lending contracts. We restrict attention to bilateral contracts, although warehouse receipts are tradeable and loans are also tradeable in an interbank market.

Labor contracts are between farmers and laborers. Farmers pay laborers $w\ell$ in exchange for laborers' investing ℓ in their technology, which then produces $y = y(i, \ell)$ units of grain at Date 1.

Deposit contracts are between warehouses and the other players, i.e., laborers, farmers, and (potentially) other warehouses. Warehouses accept grain deposits with gross rate R_t^D over one period, i.e. if player j makes a deposit of d_t^j units of grain at Date t he has the right to withdraw $R_t^D d_t^j$ units of grain at Date $t+1$. When a warehouse accepts a deposit of one unit of grain, it issues a receipt in exchange as "proof" of the deposit.

Lending contracts are between warehouses and farmers. Warehouses lend L to farmers at Date 0 in exchange for farmers' promise to repay $R^L L$ at Date 1, where R^L is the lending rate. Warehouses can lend in grain or in receipts. A loan made in receipts is tantamount to a warehouse offering a farmer a deposit at Date 0 in exchange for the farmer's promise to repay grain at Date 1. When a warehouse makes a loan in receipts, we say that it is "issuing fake receipts." We refer to a warehouse's total deposits at Date t as D_t. These deposits include both those deposits backed by grain and those granted as fake receipts.

Lending contracts are subject to a form of limited commitment on the farmers' side. Because farmers' Date 1 output is not pledgeable, they are free to divert their output and store it privately. If they deposit their output in a warehouse, the warehouse can seize the grain that the farmer owes it. If the farmer deposits his output in a warehouse, he will have his output seized, even if he deposits in a different warehouse from the one that granted him the loan. This is due to the warehouses' ability to trade loans in the interbank market, as we establish below.

We now formalize how we capture a farmer's inability to divert output if he deposits in a warehouse. We define the variable T as the total transfer from a farmer to a warehouse at Date 1; T includes both the repayment of the farmer's debt to the warehouse and the farmer's new deposit d_1^f in the warehouse. If the farmer has borrowed B at Date 0, then he has the outstanding debt of $R^L B$ at Date 1. When he transfers grain to a warehouse at Date 1, the warehouse can seize the grain if it holds the farmer's debt. If the warehouse already holds the farmer's debt, it seizes "first" $R^L B$ units of grain as repayment. If the warehouse does not already hold the farmer's debt, it buys it in the interbank market (this warehouse can enforce repayment, but the warehouse that holds the debt cannot, so there is always a mutually profitable trade).[23] Thus, the warehouse again seizes $R^L B$ units of grain as repayment. Only after full repayment of $R^L B$ does the warehouse store grain for the farmer as a deposit. Thus, the farmer's deposit at Date 1 is given by

$$d_1^f = T - \min\left\{T, R^L B\right\} = \max\left\{T - R^L B, 0\right\}. \tag{DC}$$

This says that if the farmer has not repaid his debt at Date 1, his Date 1 deposit is constrained to be zero; we call this the *deposit constraint.*

Since there is no uncertainty, without loss of generality, we can restrict attention to lending contracts where default at Date 1 never happens in equilibrium. The farmer will never default on his debt as long as repayment is incentive compatible. In other words, he must prefer to repay his debt and deposit his grain in the warehouse rather than to default on his debt and store his grain privately. If g_1^f denotes the farmer's total Date 1 grain holding[24] and $R^L B$ denotes the face value of his debt, then he repays his debt if the following incentive compatibility (IC) constraint is satisfied

$$R_1^D\left(g_1^f - R^L B\right) \geq (1-\delta) g_1^f. \tag{IC}$$

The IC constraint depends on farmers' demand for the warehouses' storage technology at Date 1. Thus, it may seem as though the warehouses' ability to collect repayment from farmers hinges on the timing of our model, namely that farmers produce at Date 1 but do not consume until Date 2. However, a standard utility function with consumption at each date and decreasing marginal utility would generate the same dependence on storage and the same incentive to repay. This is because farmers would have a strong incentive to smooth consumption between Date 1 and Date 2 and, therefore, would be dependent on warehouses to store over this period.

The timeline of moves for each player and their contractual relationships are illustrated in a timeline in Figure 5.

[23]We abstract from the price formation process in the interbank market because it does not affect the outcome. For example, if buyers and sellers determine prices by Nash bargaining, there is always trade and the farmer's repayment is unaffected by the bargaining power.

[24]In equilibrium, the farmer's total Date 1 grain holding g_1^f comprises his Date 1 output y, his Date 0 deposits gross of interest, $R_0^D d_0^f$, and his depreciated savings $(1-\delta)s_0^f$, or $g_1^f = y\big(i, \ell^f\big) + R_0^D d_0^f + (1-\delta)s_0^f$.

Figure 5: A Timeline Representation of Sequence of Moves

Date 0	Date 1	Date 2
Warehouses accept deposits D_0 lend L to farmers store s_0^b	**Warehouses** receive T from farmers accept deposits D_1 repay $R_0^D D_0$ to depositors store s_1^b	**Warehouses** repay $R_1^D D_1$ to depositors consume $c^b = s_1^b - R_1^D D_1$
Farmers borrow B from warehouses invest i and ℓ in technology y pay laborers $w\ell$ deposit d_0^f in warehouses store s_0^f	**Farmers** receive cash flow $y(i, \ell)$ transfer T to warehouses receive $R_0^D d_0^f$ from warehouses have total grain holding g_1^f deposit d_1^f in warehouses store s_1^f	**Farmers** receive $R_1^D d_1^f$ from warehouses consume $c^f = R_1^D d_1^f + (1-\delta) s_1^f$
Laborers exert labor ℓ accept wage $w\ell$ deposit d_0^l in warehouses store s_0^l	**Laborers** receive $R_0^D d_0^l$ from warehouses deposit d_1^l in warehouses store s_1^l	**Laborers** receive $R_1^D d_1^l$ from warehouses consume $c^l = R_1^D d_1^l + (1-\delta) s_1^l$

3.3 Summary of Key Assumptions

In this subsection we restate and briefly discuss the main assumptions of the model.

Assumption 1. *Output is not pledgeable.*

This assumption prevents farmers from paying laborers directly in equity or debt. If farmers' output were pledgeable, they could pay laborers after their projects paid off. Without this assumption, there would be no frictions and we could achieve the first-best allocation. Thus, this assumption creates a role for banks as providers of liquidity.

Assumption 2. *Warehouses can seize the deposits they hold.*

This assumption implies that a warehouse can enforce repayment from a farmer *as long as that farmer chooses to deposit in it.* Whenever farmers deposit in a warehouse, the warehouse can seize a portion of the deposited outcome to collect repayment from farmers. This is one key ingredient to understand the connection between warehousing/account-keeping and lending.

Assumption 3. *Grain depreciates more slowly if stored in a warehouse than if stored outside the warehouse.*

Specifically, we use the normalization that grain does not depreciate inside a warehouse and depreciates at rate $\delta \in (0, 1]$ outside a warehouse.

3.4 Individual Maximization Problems

All players take prices as given and maximize their Date-2 consumption subject to their budget constraints. Farmers' maximization problems are also subject to their incentive compatibility constraint (IC).

We now write down each player's maximization problem.

The warehouse's maximization problem is

$$\text{maximize} \quad c^b = s_1^b - R_1^D D_1 \tag{8}$$

over s_1^b, s_0^b, D_0, D_1, and L subject to

$$s_1^b = R^L L + s_0^b - R_0^D D_0 + D_1, \tag{BC$_1^b$}$$

$$s_0^b + L = D_0, \tag{BC$_0^b$}$$

and the non-negativity constraints $D_t \geq 0, s_t^b \geq 0, L \geq 0$. To understand this maximization program, note that equation (8) says that the warehouse maximizes its consumption c^b, which consists of the difference between what is stored in the warehouse at Date 1, s_1^b, and what is paid to depositors, $R_1 D_1$. Equation (BC$_1^b$) is the warehouse's budget constraint at Date 1, which says that what is stored in the warehouse at Date 1, s_1^b, is given by the sum of the interest on the loan to the farmer, $R^L L$, the warehouse's savings at Date 0, the deposits at Date 1 D_1 minus the interest the warehouse must pay on its time 0 deposits, $R_0^D D_0$. Similarly, Equation (BC$_0^b$) is the warehouse's budget constraint at Date 0, which says that the sum of the warehouse's savings at Date 0, s_0^b, and its loans L must equal the sum of the Date 0 deposits, D_0.

As established above, the deposit constraint (DC) does not depend on the warehouse the farmer deposits in. Thus, we assume the warehouse receives repayment on all of its loans directly in the problem above. This is without loss of generality, as we show formally in Appendix A.

The farmer's maximization problem is

$$\text{maximize} \quad c^f = R_1^D d_1^f + (1 - \delta) s_1^f \tag{9}$$

over $s_1^f, s_0^f, d_0^f, T, i, \ell^f$, and B subject to

$$d_1^f = \max\left\{T - R^L B, 0\right\}, \tag{DC}$$

$$\left(R_1^D - 1 + \delta\right)\left(y\left(i, \ell^f\right) + R_0^D d_0^f + (1-\delta)s_0^f\right) \geq R_1^D R^L B, \tag{IC}$$

$$T + s_1^f = y\left(i, \ell^f\right) + R_0^D d_0^f + (1-\delta)s_0^f, \tag{BC$_1^f$}$$

$$d_0^f + s_0^f + i + w\ell^f = e + B, \tag{BC$_0^f$}$$

and the non-negativity constraints $s_t^f \geq 0, d_t^f \geq 0, B \geq 0, i \geq 0, \ell^f \geq 0, T \geq 0$. The farmer's maximization program can be understood as follows. In equation (9) the farmer maximizes his Date 2 consumption c^f, which consists of his Date 1 deposits gross of interest, $R_1^D d_1^f$, and his depreciated private savings, $(1-\delta)s_1^f$. Equations (DC) and (IC) are, respectively, the deposit constraint and the incentive compatibility constraint (for an explanation see Subsection 3.2). The incentive compatibility constraint follows directly from equation (IC) in Subsection 3.2, since the farmer's Date 1 grain holding g_1^f comprises his Date 1 output y, his Date 0 deposits gross of interest, $R_0^D d_0^f$, and his depreciated savings $(1-\delta)s_0^f$, or $g_1^f = y\left(i, \ell^f\right) + R_0^D d_0^f + (1-\delta)s_0^f$. Equation (BC$_1^f$) is the farmer's budget constraint that says that the sum of his Date 1 savings, s_1^f, and his overall transfer to the warehouse, T, must equal the sum of his output y, his Date 0 deposits gross of interest, $R_0^D d_0^f$, and his depreciated savings, $(1-\delta)s_0^f$. Equation (BC$_0^f$) is the farmer's budget constraint at Date 0 which says that the sum of his Date 0 deposits, d_0^f, his Date 0 savings, s_0^f, his investment in grain i and his investment in labor, $w\ell^f$, must equal the sum of his initial endowment, e, and the amount he borrows, B.

The laborer's maximization problem is

$$\text{maximize} \quad c^l = R_1^D d_1^l + (1-\delta)s_1^l - \ell^l \tag{10}$$

over $s_1^l, s_0^l, d_1^l, d_0^l$, and ℓ^l subject to

$$d_1^l + s_1^l = R_0^D d_0^l + (1-\delta)s_0^l, \tag{BC$_1^l$}$$

$$d_0^l + s_0^l = w\ell^l, \tag{BC$_0^l$}$$

and the non-negativity constraints $s_t^l \geq 0, d_t^l \geq 0, \ell^l \geq 0$. The laborer's maximization program can be understood as follows. In equation (10) the laborer maximizes his Date 2 consumption c^l, which consists of his Date 1 deposits gross of interest, $R_1^D d_1^l$, and his depreciated private savings, $(1-\delta)s_1^l$. Equation (BC$_1^l$) is the laborer's budget constraint that says that the sum of his Date 1 savings, s_1^l, and his Date 1 deposits, d_1^l, must equal the sum of his Date 0 deposits gross of interest, $R_0^D d_0^l$, and his depreciated savings, $(1-\delta)s_0^l$. Equation (BC_0^l) is the laborer's budget constraint at Date 0 which says that the sum of his Date 0 deposits, d_0^l, and his Date 0 savings, s_0^l, must equal his labor income $w\ell^l$.

3.5 Equilibrium Definition (Second Best)

The equilibrium is a profile of prices $\langle R_t^D, R^L, w\rangle$ for $t \in \{1,2\}$ and a profile of allocations $\langle s_t^j, d_t^f, d_t^l, D_t, L, B, \ell^l, \ell^f\rangle$ for $t \in \{1,2\}$ and $j \in \{b,f,l\}$ that solves the warehouses' problem, the farmers' problem, and the laborers' problem defined in Section 3.4 and satisfies the market clearing conditions for the labor market, the lending market, the grain market and deposit market at each date:

$$\ell^f = \ell^l \tag{MC$^\ell$}$$

$$B = L \tag{MC^L}$$

$$i + s_0^f + s_0^l + s_0^b = e \tag{MC$_0^g$}$$

$$s_1^f + s_1^l + s_1^b = (1-\delta)s_0^f + (1-\delta)s_0^l + s_0^b + y \tag{MC$_1^g$}$$

$$D_0 = d_0^f + d_0^l \tag{MC$_0^D$}$$

$$D_1 = d_1^f + d_1^l. \tag{MC$_1^D$}$$

3.6 Parameter Restrictions

In this subsection we impose two restrictions on the deep parameters of the model. The first ensures that farmers' production technology generates sufficiently high output that the investment has positive NPV in equilibrium, and the second ensures that the incentive problem that results from the non-pledgeablity of farmers' output is sufficiently severe to generate a binding borrowing constraint in equilibrium. Note that since the model is linear, if a farmer's IC does not bind, he will scale his production infinitely.

Parameter Restriction 1. *The farmers' technology is sufficiently productive,*

$$A > 1 + \frac{1}{\alpha}. \tag{11}$$

Parameter Restriction 2. *Depreciation from private storage is not too high,*

$$\delta A < 1. \tag{12}$$

4 Solving the Model

This section has three main parts. In the first part we derive some benchmark solutions with which we can compare the second best. In the second part we derive the second best. In the third part we analyze the second best.

4.1 Benchmarks

We consider two benchmarks, before proceeding to solve for the second best. First, we solve for the first-best allocation. Second, we solve for the outcome given that the warehouse cannot issue fake receipts.

4.1.1 Benchmark: First Best

We now consider the first-best allocation, i.e. the allocation that maximizes utilitarian welfare subject only to the aggregate resource constraint. Here we consider the allocation that would maximize total output subject only to market clearing conditions. Since the utility, cost, and production functions are all linear, in the first-best allocation, all resources are allocated to the most productive players at each date. At Date 0 the farmers are the most productive and at Date 1 the warehouses are the most productive. Thus, all grain is held by farmers at Date 0 and by warehouses at Date 1. Laborers exert labor in proportion $1/\alpha$ of the total grain invested to maximize production.

Proposition 1. (First-best Allocation) *The first-best allocation is as follows:*

$$\ell_{\text{fb}} = \alpha e, \tag{13}$$

$$i_{\text{fb}} = e. \tag{14}$$

4.1.2 Benchmark: No Fake Receipts

Consider a benchmark model in which warehouses cannot issue any receipts that are not backed by grain. This corresponds to adding an additional constraint in the warehouses' problem in Subsection 3.4. Since farmers have the entire endowment at Date 0, the warehouse cannot lend. Thus, farmers simply divide their endowment between their capital investment i and their labor investment ℓ; their budget constraint reads

$$i + w\ell = e. \tag{15}$$

The Leontief production function implies that they will always make capital investments equal to the fraction α of their labor investments, or

$$\alpha i = \ell. \tag{16}$$

We summarize the solution to this benchmark model in Proposition 2 below.

Proposition 2. (Benchmark Case with No Fake Receipts) *When warehouses cannot issue fake receipts, the equilibrium is as follows:*

$$\ell_{\text{nr}} = \frac{\alpha e}{1+\alpha}, \tag{17}$$

$$i_{\text{nr}} = \frac{e}{1+\alpha}. \tag{18}$$

Note that even though warehouses do not improve allocational efficiency by extending credit to farmers, they nonetheless lead to efficiency gains, because they provide efficient storage of grain from Date 1 to Date 2.

4.2 Derivation of the Second-Best Solution (with Fake Receipts)

We now solve the model to characterize the second best. We proceed as follows. First, we pin down the equilibrium deposit rates, lending rates and wages. Then we show that the model collapses to the farmer's problem which we then solve to characterize the equilibrium.

4.2.1 Preliminary Results for the Second-best

Here we state three results that completely characterize all the prices in the model, namely the two deposit rates R_0^D and R_1^D, the lending rate R^L, and the wage w. We then show that, given the equilibrium prices, farmers and laborers will never store grain privately. The results all follow from the definition of competitive equilibrium with risk-neutral agents.

The first two results say that the risk-free rate in the economy is one. This is natural, since the warehouses have a scalable storage technology with return one.

Lemma 1. (Deposit Rates at $t = 0$ and $t = 1$) $R_0^D = R_1^D = 1$.

Now we turn to the lending rate. Since the farmers' incentive compatibility constraint ensures that loans are riskless and warehouses are competitive, warehouses also lend to farmers at rate one.

Lemma 2. (Lending Rates) $R^L = 1$.

Finally, since laborers have a constant marginal cost of labor, the equilibrium wage must be equal to this cost; this says that $w = 1$, as summarized in Lemma 3 below.[25]

Lemma 3. (Wages) $w = 1$.

These results establish that the risk-free rate offered by warehouses exceeds the rate of return from private storage, or $R_0^D = R_1^D = 1 > 1-\delta$. Thus, farmers and laborers do not wish to make use of their private storage technologies. The only time a player may choose to store grain outside a warehouse is if a farmer diverts his output; however, the farmer's incentive compatibility constraint ensures he will not do this. Corollary 1 below summarizes this reasoning.

Corollary 1. (Grain Storage) *Farmers and laborers do not store grain, i.e.,* $s_0^l = s_0^f = s_1^l = s_1^f = 0$.

4.2.2 Equilibrium Characterization (Second Best)

Now we characterize the equilibrium (second-best outcome) of the model. We proceed as follows. First, we show that given the equilibrium prices established in Subsection 4.2.1 above, laborers and warehouses are indifferent among all allocations. We then establish that a solution to the farmers' maximization problem, given the equilibrium prices, is a solution to the model.

The prices R_0^D, R_1^D, R^L, and w are determined exactly so that the markets clear given that agents are risk-neutral. In other words, they are the unique prices that prevent the demands of warehouses or laborers from being infinite. This is the case only if warehouses are indifferent between demanding and supplying deposits and loans at rates R_0^D, R_1^D, and R^L and laborers are indifferent between supplying or not supplying labor at wage w, as summarized in Lemma 4 below.

Lemma 4. (Warehouse and Labor Preferences) *Given the equilibrium prices,* $R_0^D = R_1^D = R^L = w = 1$*, warehouses are indifferent among all deposit and loan amounts and laborers are indifferent among all labor amounts.*

Lemma 4 implies that, given the equilibrium prices, warehouses will absorb any excess demand left by the farmers. In other words, given the equilibrium prices established in Subsection 4.2.1 above, for any solution to the farmer's individual maximization problem, laborers' and warehouses' demands are such that markets clear.

We have thus established that the equilibrium allocation is given by the solution to the farmer's problem, given the equilibrium prices. Thus, to find the equilibrium,

[25]Note that we have omitted the effect of discounting in the preceding argument—laborers work at Date 0 and consume at Date 2; discounting is safely forgotten, though, since the laborers have access to a riskless storage technology with return one via the warehouses, as established above.

we maximize the farmer's Date 2 consumption subject to his budget and incentive constraints, given the equilibrium prices. In other words, we have reduced the problem of solving for the equilibrium—solving the warehouse's problem, farmer's problem, and laborer's problem in Subsection 3.4 and the market clearing conditions in Subsection 3.5—to solving a single constrained maximization problem. We state this problem in Lemma 5 below.

LEMMA 5. (SECOND-BEST PROGRAM) *The equilibrium allocation solves the problem to*

$$\text{maximize} \quad d_1^f \tag{19}$$

subject to

$$\delta\Big(y\big(i, \ell^f\big) + d_0^f\Big) \geq B, \tag{IC}$$

$$d_1^f + B = y\big(i, \ell^f\big) + d_0^f, \tag{BC$_1^f$}$$

$$d_0^f + i + \ell^f = e + B, \tag{BC$_0^f$}$$

and $i \geq 0, \ell^f \geq 0, B \geq 0, d_0^f \geq 0,$ *and* $d_1^f \geq 0.$

Solving the program above allows us to characterize the equilibrium allocations.

PROPOSITION 3. (EQUILIBRIUM VALUES OF DEBT, LABOR AND INVESTMENT) *The (second-best) equilibrium allocation is as follows:*

$$B = \frac{\delta A \alpha e}{1 + \alpha\big(1 - \delta A\big)}, \tag{20}$$

$$\ell = \frac{\alpha e}{1 + \alpha\big(1 - \delta A\big)}, \tag{21}$$

$$i = \frac{e}{1 + \alpha\big(1 - \delta A\big)}. \tag{22}$$

The equilibrium above is the solution of a system of linear equations, from the binding budget constraint and the farmers' binding incentive constraints. Observe that lending, labor, and investment are increasing in depreciation. That is to say that the worse is the farmer's private storage technology, the better is the equilibrium outcome. The reason is that it loosens his incentive constraint, making depositing more attractive at Date 1. This intuition will reappear in the next section, in which we analyze the equilibrium in detail.

4.3 Analysis of the (Second-best) Equilibrium

In this section we present the analysis of the (second-best) equilibrium in the context of liquidity creation.

4.3.1 Liquidity Creation

In this subsection we turn to the funding liquidity a warehouse creates. We begin with the definition of a "liquidity multiplier," which describes the total investment (grain investment plus labor investment) that farmers can undertake at Date 0 relative to the total endowment e.

Definition 1. *The* <u>*liquidity multiplier* Λ</u> *is the ratio of the equilibrium investment in production* $i + w\ell$ *to the total grain endowment in the economy* e*,*

$$\Lambda := \frac{i + w\ell}{e}. \tag{23}$$

The liquidity multiplier Λ reflects farmers' total investment at Date 0. To focus on the role of warehouses in creating *additional* liquidity, we will refer to the "total liquidity created by warehouses" as the total investment $i + w\ell$ minus the initial liquidity e, which is given by $i + w\ell - e = (\Lambda - 1)e$.

Proposition 4. (Fake Receipts and Liquidity Creation) *Banks create liquidity only when they can issue fake receipts. In equilibrium, the liquidity multiplier is*

$$\Lambda = \frac{1 + \alpha}{1 + \alpha\big(1 - \delta A\big)} > 1, \tag{24}$$

whereas, in the benchmark model with no receipts, the liquidity multiplier is one, denoted $\Lambda_{\text{nr}} = 1$.

This result implies that it is the warehouses' ability to *make loans in fake receipts, not its ability to take deposits, that creates liquidity in the economy.* Warehouses lubricate the economy because they lend in fake receipts rather than in grain. They can do this because of their dual function: they keep accounts (i.e. warehouse grain) and also make loans. This is the crux of farmers' incentive constraints: because warehouses provide valuable warehousing services, farmers go to these warehouse-banks and deposit their grain, which is then also the reason why they repay their debts.

To cement the argument that liquidity creation results only from warehouses' lending in fake receipts, we now relate the quantity of fake receipts that the warehouse issues to the liquidity multiplier. The number of fake receipts the warehouse issues at Date 0 is given by the total number of receipts it issues D_0 less the total quantity of grain it stores s_0^b;[26] in equilibrium, this is given by

$$D_0 - s_0^b = \frac{\delta A \alpha e}{1 + \alpha\big(1 - \delta A\big)}. \tag{25}$$

[26]The grain market clearing condition implies that $s_0^b = e - i$ and warehouses' Date-0 budget constraint says $D_0 = s_0^b + L$, where $L = B$ by loan market clearing and B is given in Proposition 3.

Comparing the expression above with the formula for Λ in Proposition 4 leads to the next result.

Corollary 2. (Total Liquidity Creation) *The total liquidity created by warehouses equals the number of fake receipts the warehouse issues*

$$(\Lambda - 1)\, e = D_0 - s_0^b. \tag{26}$$

We now analyze the effect of the private storage technology—i.e. the depreciation rate δ—on warehouses' liquidity creation. Differentiating the liquidity multiplier Λ with respect to δ:

$$\frac{\partial \Lambda}{\partial \delta} = \frac{\alpha A}{\big(1 + \alpha(1 - \delta A)\big)^2} > 0. \tag{27}$$

This leads to:

Corollary 3. (Warehouse Efficiency and Liquidity Creation) *The more efficiently warehouses can store grain relative to farmers (the higher is δ), the more liquidity warehouses create by issuing fake receipts.*

Corollary 3 seems counterintuitive at first blush—a *decrease* in the efficiency in private storage leads to an *increase* in overall efficiency. The reason is that δ measure the storage advantage that the warehouse has over private storage, so a higher δ weakens farmers' incentive to divert capital, thereby allowing banks to create more liquidity. We return to this result when we discuss central bank policy in the next section. This result also suggests an empirical implication. To the extent that warehouses have "power" in enforcing contracts, we should expect warehousing services to be more important in countries with weaker property rights.

4.3.2 Fractional Reserves

We now proceed to analyze warehouses' balance sheets. Absent reserve requirements, do they still store any grain or is everything loaned out? Our next result addresses this question.

Proposition 5. (Deposit Reserves Held by Warehouses) *Warehouses hold a positive fraction of grain at $t = 0$, in equilibrium,*

$$s_0^b = e - i = \frac{\alpha\big(1 - \delta A\big)e}{1 + \alpha\big(1 - \delta A\big)} > 0. \tag{28}$$

This result may be a bit surprising because the constant-returns-to-scale farmers' technology means that farmers would prefer to invest all grain in the economy in their technology, leaving no grain for storage. The reason this result holds is that farmers' incentive constraints put an endogenous limit on the amount that each farmer can borrow. Farmers cannot borrow enough from warehouses to pay laborers entirely in fake receipts as they would in the first best. Rather, they pay warehouses in a combination of fake receipts and real grain. Laborers deposit the grain they receive in warehouses for storage.

Note that in our model, the storage of grain by warehouses at Date 0 is inefficient. Grain could be put to better use by farmers (in conjunction with labor paid for in fake receipts). Thus, a policymaker in our model actually wishes to reduce warehouse holdings or bank (liquidity) reserves, to have the economy operate more efficiently. We say more about this in the next section.

5 Welfare and Policy

In this section we consider the implications of four policies, all of which have been debated by policy-makers after the financial crisis of 2007–2009. These are: (i) liquidity requirements for banks, (ii) narrow banking, (iii) capital for banks, and (iv) tightening monetary policy. We end with a subsection in which we apply a mechanism design approach to our environment.

5.1 Liquidity Requirements, Liquidity Creation and Narrow Banking

Liquidity requirements. Basel III, the Basel Committee on Banking Supervision's third accord, extends international financial regulation to include so-called liquidity requirements. Specifically, Basel III mandates that banks must hold a sufficient quantity of liquidity to ensure that a "liquidity ratio" called the Liquidity Coverage Ratio (LCR) is satisfied. The ratio effectively forces banks to invest a portion of their assets in cash and cash-proximate marketable securities. The rationale is that banks should be able to liquidate a portion of their balance sheets expeditiously to withstand withdrawals in a crisis.

In our model, the LCR imposes a limit on the ratio of loans that a bank (warehouse) can make relative to deposits (grain) it stores. This is exactly a limit on the quantity of fake receipts a bank can issue or a limit on liquidity creation.

We now make this more formal. Consider a liquidity regulation that, like the LCR, mandates that a bank hold a proportion θ of its assets in liquid assets, or

$$\frac{\text{liquid assets}}{\text{total assets}} \geq \theta. \tag{29}$$

In our model, the warehouses' liquid assets are the grain they store and their total assets are the grain they store plus the loans they make. Thus, within the model, the liquidity regulation described above prescribes that, at Date 0,

$$\frac{s_0^b}{B + s_0^b} \geq \theta. \tag{30}$$

We see immediately by rewriting this inequality that this regulation imposes a cap on bank lending,

$$B \leq \frac{1-\theta}{\theta} s_0^b. \tag{31}$$

We now have:

PROPOSITION 6. (EFFECT OF LIQUIDITY REQUIREMENTS) *Whenever the required liquidity ratio θ is such that*

$$\theta > 1 - \delta A, \tag{32}$$

liquidity regulation inhibits liquidity creation—and thus farmers' investment—below the equilibrium level.

In our model, liquidity requirements—when binding—reduce lending below that dictated by incentive constraints. This is inefficient.

Narrow banking. Advocates of so-called *narrow banking* have argued that banks should hold *only* liquid securities as assets, with some arguing for banks to invest only in Treasuries.[27] If we view banks' investments in Treasury securities as the functional equivalent of deposits with the Federal Reserve (which count as bank reserves), then this is tantamount to one hundred percent reserves. In our model, this corresponds to $\theta = 1$ in the analysis of the LCR, which reduces to the benchmark in which warehouses cannot make loans. We state this as a proposition for emphasis.

PROPOSITION 7. (NARROW BANKING) *The requirement of narrow banking is equivalent to the benchmark in which warehouses cannot issue fake receipts (Subsection 4.1). In this case there is no liquidity creation, $\Lambda_{\text{nr}} = 1$.*

Thus far, we have focused on the effects of liquidity requirements on bank lending. However, advocates of liquidity requirements often focus on their effects on financial stability, not funding liquidity. In Subsection 6.2, we include the possibility of a bank run (or "warehouse run") and explore the connection between liquidity requirements and financial stability. Our analysis suggests that higher liquidity requirements may also have a negative effect on financial stability, because they increase depositors' incentive to run.

[27] See Kay (2010) and the review by Pennacchi (2012).

5.2 Bank Capital and Liquidity Creation

Bank capital has played no role in the analysis so far because of the presumed credibility of the warehouse's own commitments. We now extend the model to analyze the implications of changes in bank capital for warehouse liquidity creation.[28] In this extension, we endow warehouses with equity e^b at Date 1 and add a pledgeablity problem for the warehouse when it accepts deposits. Specifically, after a warehouse accepts deposits, it has the following choice: it can either divert grain and store it privately or not divert grain and store it in the warehouse. If it diverts the grain, the depositors will not be able to claim it, but it will depreciate at rate δ. If the warehouse does not divert, depositors will be able to claim it, but it will not depreciate. We show that warehouse equity has an important function: it gives the warehouse the incentive *not* to divert deposits.

The results of this section follow from the analysis of the warehouse's incentive constraint: depositors store in a warehouse at Date 1 only if the warehouse prefers not to divert deposits. Its payoff, if it diverts, is given by the depreciated value of its equity plus its deposits, or $(1-\delta)(e^b + D_1)$. Its payoff, if it does not divert, is the value of its equity plus its deposits less its repayment to its depositors, or $e^b + D_1 - R_1^D D_1$. Since $R_1^D = 1$ by Lemma 1, the warehouses incentive compatibility constraint at Date 1[29] is

$$(1-\delta)(e^b + D_1) \leq e^b. \tag{33}$$

Thus, the second-best equilibrium outcome summarized in Proposition 3 is obtained only if

$$\frac{e^b}{D_1} \geq \frac{1-\delta}{\delta}. \tag{34}$$

This is a constraint which says that the second-best is attained only if warehouse's capital ratio is sufficiently high. Substituting the equilibrium value of D_1 leads to

PROPOSITION 8. (ROLE OF WAREHOUSE EQUITY) *The second-best equilibrium in Proposition 3 is attained only if warehouse equity is sufficiently high, or*

$$e^b \geq \hat{e}^b := \frac{1-\delta}{\delta}\frac{\alpha\big[1+(1-\delta)A\big]}{1+\alpha(1-\delta A)}e. \tag{35}$$

If warehouse equity is below $\hat{e}^b$, the warehouse's incentive constrain binds (and the farmer's incentive constraint does not) and an increase in warehouse equity loosens

[28]Because we do not have bank failures and crises in our baseline model, our analysis likely understates the value and role of bank capital. Calomiris and Nissim (2014) document that the market is attaching a higher value to bank capital after the 2007–09 crisis.

[29]If the incentive constraint is satisfied at Date 1, when deposits are high because farmers deposit their output in warehouses, it is also satisfied at Date 0, when deposits are relatively low.

THE LIQUIDITY MULTIPLIER AS A FUNCTION OF WAREHOUSE EQUITY e^b

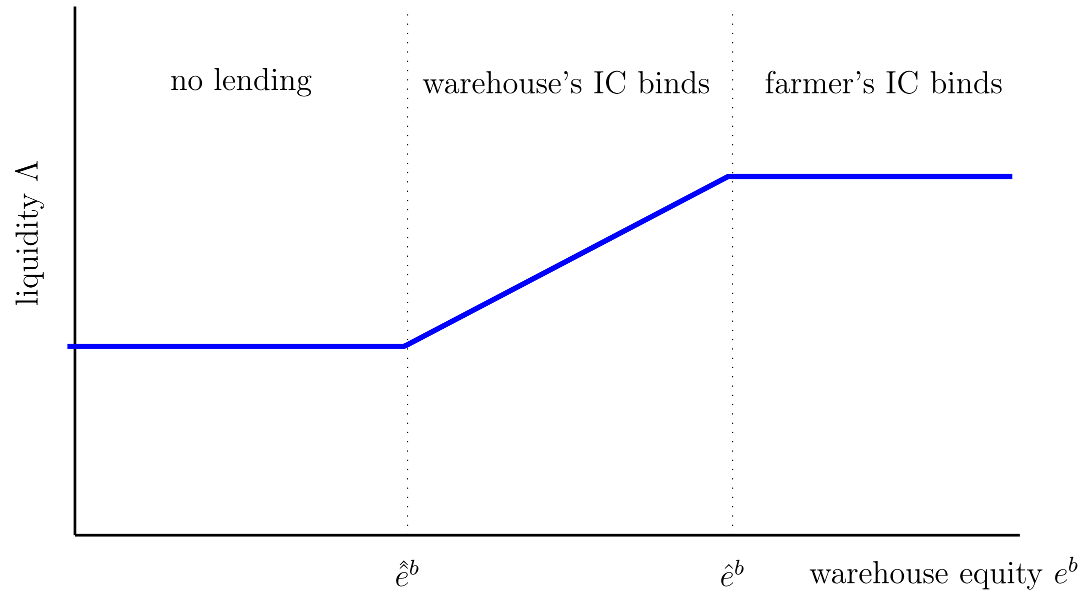


Figure 6: The graph depicts the liquidity multiplier Λ as a function of warehouse equity as analyzed in Subsection 5.2.

the warehouse's incentive constraint. This allows it to accept more deposits. Since accepting more deposits allows it to obtain a larger repayment from borrowers, this also allows the warehouse to make more loans. In other words:

PROPOSITION 9. (LIQUIDITY CREATION FOR DIFFERENT LEVELS OF WAREHOUSE CAPITAL) *When warehouse equity e^b is below a threshold,*

$$\hat{\hat{e}}^b := \frac{\alpha(1-\delta)(1+A)e}{(1+\alpha)\delta}, \tag{36}$$

there is no lending and hence no liquidity creation. For $e^b \in (\hat{\hat{e}}^b, \hat{e}^b]$, liquidity creation is strictly increasing in warehouse equity e^b. For $e^b > \hat{e}^b$, warehouse equity has no effect on liquidity creation. Specifically,

$$\Lambda = \begin{cases} 1 \quad \text{if} \quad e^b \leq \hat{\hat{e}}^b, \\ \dfrac{1+\alpha}{\alpha A - 1}\left(\dfrac{\delta}{1-\delta}\,\dfrac{e^b}{e} - 1\right) \quad \text{if} \quad e^b \in (\hat{\hat{e}}^b, \hat{e}^b], \\ \dfrac{1+\alpha}{1+\alpha\big(1-\delta A\big)} \quad \text{if} \quad e^b > \hat{e}^b. \end{cases} \tag{37}$$

The expression for Λ in this proposition, illustrated in Figure 6, says that when warehouse equity is very low, the incentive problem is so severe that warehouses do not lend at all. As equity increases, warehouses start lending and the amount they lend increases linearly until the farmer's incentive constraint binds. Above this threshold, an increase in equity has no further effect, because the borrowers' (farmers') incentive constraints bind, and if they were to take larger loans, they would not repay.

Our result that higher bank capital expands the bank's lending capacity and hence enhances ex ante liquidity creation stands in contrast to much of the existing literature on bank liquidity creation. In models like Bryant (1980) and Diamond and Dybvig (1983), there is no discernable role for bank capital, and models like Diamond and Rajan (2001) argue that higher bank capital will diminish liquidity creation by banks. Two exceptions are Holmström and Tirole (1997) and Rampini and Viswanathan (2015). In Holmström and Tirole (1997) higher bank capital gives banks an incentive to monitor borrowers and thus mitigates a moral hazard problem, allowing them to lend more. Bank capital in our model also mitigates a moral hazard problem, but it allows banks to *take more deposits*. This, in turn, allows them to lend more, since warehouse-banks enforce repayment via deposit-taking. Rampini and Viswanathan (2015) show that intermediary capital is important in a model in which intermediaries serve as "collateralization specialists." This because, as in Holmström and Tirole (1997), well-capitalized intermediaries can efficiently funnel funds from savers to the productive sector. In our model, in contrast, intermediaries lend via fake receipts even without raising funds from savers.

5.3 Monetary Policy

In our basic model, there is no fiat money or a role for a central bank. We now extend the model to analyze these issues, in particular the implications of changes in monetary policy on warehouse liquidity creation. We define the central bank rate R^{CB} as the (gross) rate at which warehouses can deposit with the central bank.[30] This is analogous to the storage technology of the warehouse yielding return R^{CB}. In this interpretation of the model, grain is central bank money and warehouse receipts are private money.

We first state the necessary analogs of the parameter restrictions in Subsection 3.6. Note that they coincide with Parameter Restriction 1 and Parameter Restriction 2 when $R^{\mathrm{CB}} = 1$, as in the baseline model.

Parameter Restriction 1′. *The farmers' technology is sufficiently productive,*

$$A > \frac{1}{R^{\mathrm{CB}}} + \frac{R^{\mathrm{CB}}}{\alpha}. \tag{38}$$

[30]We are considering a rather limited aspect of central bank monetary policy here, thereby ignoring things like the role of the central bank in setting the interest rate on interbank lending, as in Freixas, Martin and Skeie (2011), for example.

Parameter Restriction 2′. *Depreciation from private storage is not too fast,*

$$A\left(R^{\mathrm{CB}} - 1 + \delta\right) < 1. \tag{39}$$

The preliminary results of Subsection 4.2.1 lead to the natural modifications of the prices. In particular, due to competition in the deposit market, the deposit rates equal the central bank rate. Further, because laborers earn interest on their deposits, they accept lower wages. Thus we have:

Lemma 6. (Interest Rates and Wages with a Central Bank) *When warehouses earn the central bank rate R^{CB} on deposits, in equilibrium, the deposit rates, lending rate, and wage are as follows:*

$$R_0^D = R_1^D = R^L = R^{\mathrm{CB}} \tag{40}$$

and

$$w = \left(R^{\mathrm{CB}}\right)^{-2}. \tag{41}$$

The crucial takeaway from the result is that the warehouse pays a higher deposit rate when the central bank rate is higher. This means that the farmer's incentive constraint takes into account a higher return from depositing in a warehouse, but the same depreciation rate from private storage. Formally, with the central bank rate R^{CB}, the farmer's incentive constraint at Date 1 reads

$$R^{\mathrm{CB}}\left(y - R^{\mathrm{CB}}B\right) \geq (1-\delta)y \tag{42}$$

or

$$B \leq \frac{1}{R^{\mathrm{CB}}}\left(1 - \frac{1-\delta}{R^{\mathrm{CB}}}\right)y. \tag{43}$$

Observe that whenever farmers are not too highly levered—$B < y\left(2R^{\mathrm{CB}}\right)^{-2}$—increasing R^{CB} loosens the incentive constraint. The reason is that it makes warehouse storage relatively more attractive at Date 1, inducing farmers to repay their debt rather than diverting capital.[31]

Proposition 10. (Monetary Policy and Liquidity Creation) *A tightening of monetary policy (an increase in R^{CB}) increases liquidity creation Λ as long as $\alpha + 2R^{\mathrm{CB}}(1-\delta) > \left(R^{\mathrm{CB}}\right)^2$ (otherwise it decreases liquidity creation).*

This contrasts with the established idea that a lowering of the interest rates by the

[31] The reason that increasing R^{CB} does not loosen the constraint when B is high, it that it also increases the lending rate between Date 0 and Date 1.

central bank stimulates bank lending.[32] In our model, *high interest rates allow banks to lend more*. This result complements Corollary 3 which says that liquidity creation is increasing in the depreciation rate δ. Both results say that the better warehouses are at storing grain relative to farmers, the more warehouses can lend.

5.4 A Mechanism Design Approach to the Second Best

We now briefly discuss a mechanism design approach to our model and results. This approach suggests considering all incentive-feasible allocations, given only the preferences and technologies of the players, rather than focusing on a particular equilibrium concept. In other words, rather than considering markets a primitive of the model, we consider all the allocations that can be implemented with any general mechanism for players' interactions.

We state our main finding as a proposition for emphasis and provide a verbal proof in the text.

PROPOSITION 11. (MECHANISM DESIGN AND THE SECOND-BEST EQUILIBRIUM) *If the worst feasible punishment for farmers is autarky, then the second-best equilibrium summarized in Proposition 3 is optimal in the sense that it maximizes output and utilitarian welfare among all incentive-feasible allocations.*

We divide the proof of the proposition into three steps. In Step 1, we explain that a mechanism that implements the most severe feasible punishments can implement the (constrained) optimal outcome. In Step 2, we argue that the most severe punishments in our environment are the exclusion from warehousing. In Step 3, we show that our environment with Walrasian markets in which warehouses can seize their deposits implements these punishments.

Step 1. A mechanism can implement an outcome if the outcome is incentive compatible given the mechanism. Increasing the severity of punishments corresponds to loosening incentive constraints, which expands the set of implementable outcomes. Hence, increasing the severity of punishments expands the set of implementable outcomes.

Step 2. In our environment, punishments must be administered at Date 1 (at Date 2 agents consume, so we are effectively already in autarky and at Date 0 it is too early to punish them for anything). At Date 1, there are only two technologies, private storage and warehouse storage. Thus, the only benefit the environment provides beyond autarky is access to warehousing. In other words, the worst possible punishment is exclusion from warehousing.

[32] See, for example, Keeton (1993). Mishkin (2010) provides a broad assessment of monetary policy, bank lending, and the role of the central bank.

Step 3. The only limit to commitment in our environment comes from the non-pledgeability of farmers' output—the farmer is the only player who might not fulfill his promise. However, given the interbank market, anything the farmer deposits in the warehouse ultimately can be seized. Thus, the only way that a farmer can avoid repayment at Date 1 is by storing privately. This is equivalent to saying that if a farmer breaks his promise, he cannot store in a warehouse—he receives the autarky payoff. Thus, our model imposes the most severe feasible punishments on defecting players. As a result (from Step 1), our model implements the optimal incentive-feasible outcome.

6 Robustness

In this section we show that our mechanism is robust to two changes in the model specification. First, we show that the incentive mechanism is robust to the possibility of the farmer consuming at the interim date. Second, we show that our analysis of liquidity requirements in Subsection 5.1 is robust to the inclusion of bank runs—financial fragility concerns do not overturn our results that liquidity requirements inhibit liquidity creation.

6.1 Consumption at Date 1

Because farmers produce at Date 1 and consume only at Date 2, they need to save between Date 1 and Date 2. Thus, they are dependent on warehouses for efficient storage. In this subsection we consider a different specification of farmers' preferences, in which farmers have log utility and consume at Date 1 and Date 2. We show that our mechanism is robust to the possibility of allowing farmers to consume at Date 1. The intuition for this is that with log utility the farmer has incentive to smooth consumption across dates. Thus, he always has incentive to save something for Date 2.

Suppose now that the farmer has log utility and consumes at both at Date 1 and at Date 2. Denoting consumption at Date t by c_t, a farmer's total payoff is given by

$$U(c_1, c_2) = \log c_1 + \log c_2. \tag{44}$$

If a farmer has grain y at Date 1, it is incentive compatible for him to repay his debt if he prefers to deposit and repay than to divert, where now if he diverts he may either store privately, as before, or consume immediately. His payoff if he does not divert is

$$U_{\text{deposit}} = \max \left\{ u(c_1) + u(c_2) \;\middle|\; c_2 = R_D(y - c_1 - R_L L) \right\}. \tag{45}$$

Solving the program with the first-order approach gives

$$U_{\text{deposit}} = \log\left(\frac{y - R_L L}{2}\right) + \log\left(\frac{R_D(y - R_L L)}{2}\right). \tag{46}$$

Likewise, the payoff if the farmer does divert is

$$U_{\text{divert}} = \max\left\{ u(c_1) + u(c_2) \;\middle|\; c_2 = (1-\delta)(y - c_1) \right\}. \tag{47}$$

Solving this program with the first-order approach gives

$$U_{\text{divert}} = \log\left(\frac{y}{2}\right) + \log\left(\frac{(1-\delta)y}{2}\right). \tag{48}$$

Now we can write the farmer's incentive constraint with log utility. He prefers to deposit than to divert if $U_{\text{deposit}} > U_{\text{divert}}$ in equations (45) and (47) above. This reduces to the following borrowing constraint

$$L \leq \frac{\sqrt{R_D} - \sqrt{1-\delta}}{\sqrt{R_D} R_L} y \tag{49}$$

were we have used the fact that $\log x + \log y = \log xy$ and simplified. If we substitute $R_D = R_L = 1$ and use the Taylor approximation, we can express the borrowing constraint as follows:

$$L \leq \left(1 - \sqrt{1-\delta}\right) y \approx \frac{\delta y}{2}. \tag{50}$$

This is exactly the incentive constraint in the model with linear utility and consumption only at Date 2 and rate of depreciation $\delta/2$. Thus, we conclude that our basic mechanism is not affected by consumption at the interim date, although it may attenuate the importance of savings. Specifically, it corresponds to lowering the rate of depreciation.

6.2 Financial Fragility

In Subsection 5.1, we showed that higher liquidity requirements decrease bank liquidity creation by inhibiting lending. However, the oft-stated purpose of liquidity requirements is to enhance financial stability.[33] The argument goes that a bank with more liquid reserves will be able to withstand more withdrawals or a larger "run" from its creditors, creating stability. In this section we address this by extending the model to include a bank run game among depositors. We show that more liquid reserves may make a financial system more *fragile* in our setting. The reason is that while liquid reserves do

[33]The Basel Committee on Banking Supervision states that "The LCR is one of the Basel Committee's key reforms to strengthen global capital and liquidity regulations with the goal of promoting a more resilient banking sector. The LCR promotes the short-term resilience of a bank's liquidity risk profile" (see http://www.bis.org/publ/bcbs238.htm).

Figure 7: Payoff Matrix of the Bank Run Game at Date 0^+

	$\lambda \leq \theta$	$\lambda > \theta$
Withdraw	$1-\delta$	$\dfrac{(1-\delta)h(\theta)}{\lambda}$
$\neg$ Withdraw	1	0

indeed allow a bank to withstand a bigger run, they also make depositors more prone to running the bank.

We consider a warehouse with total deposits θ at Date 0 and add an additional stage immediately after Date 0, called Date 0^+. At this stage, each depositor may demand to withdraw grain or leave it in the warehouse. We use the notation λ to refer to the total amount of grain demanded by all depositors at Date 0^+. If $\lambda \leq \theta$, then the warehouse has sufficient reserves to pay all withdrawing depositors. It remains solvent. Withdrawing depositors take out their grain and store it privately, letting it depreciate at rate δ. Non-withdrawing depositors do not take out their grain, but can claim it at Date 1. Thus, they avoid depreciation. If $\lambda > \theta$, then the warehouse does not have sufficient reserves to pay all withdrawing depositors. The warehouse is insolvent. It liquidates the reserves for a positive amount $h(\theta)$—where $h(\theta) < \theta$, reflecting the costs of early liquidation[34]—and it distributes them among withdrawing depositors according to a pro rata rule, i.e. for each unit of grain demanded, a withdrawing depositor receives $h(\theta)/\lambda$ units of grain. Since the warehouse is insolvent and closes, depositors who have not withdrawn cannot cash in their receipts at Date 1. They receive zero. The payoffs from withdrawing or not withdrawing a unit of grain as a function of λ are summarized in Figure 7.

At Date 0^+ depositors now play a coordination game. There are multiple Nash equilibria as long as $\delta \in (0,1)$. In particular, there are two pure strategy Nash equilibria, one in which all depositors withdraw (a bank run) and another in which no depositors withdraw.

In order to analyze the effect of liquid reserves θ on financial stability, we select an

[34]In the case in which the warehouse is a granary or a goldsmith's safe, the difference $\theta - h(\theta)$ could represent the transportation costs of making additional withdrawals. In the case in which the warehouse represents a modern bank or a custodian, $\theta - h(\theta)$ represents the costs of unexpected liquidation of liquid assets, for example due to price impact or transactions costs.

equilibrium using global games techniques.[35] We suppose that the rate of depreciation δ is random and depositors observe it with a small amount of noise.[36] In the limit as this noise vanishes, the game has a unique equilibrium, depending on the realization of δ. There is a number δ^* such that if $\delta > \delta^*$ no one withdraws and if $\delta < \delta^*$ everyone withdraws—i.e. there is a bank run.

The probability of a run is thus the probability that δ is less than δ^*. Hence, the larger is δ^* the higher is the probability of a bank run; δ^* thus measures *financial fragility.* To analyze the effect of reserve requirements on financial fragility, we ask how δ^* varies with θ.

By a standard result (see Morris and Shin (2003)), δ^* is the solution of the following equation:

$$\int_0^1 \text{don't withdraw payoff}\,(\delta)\,d\lambda = \int_0^1 \text{withdraw payoff}\,(\delta)\,d\lambda \tag{51}$$

i.e.

$$\int_0^1 \mathbb{1}_{\{\lambda\leq\theta\}} d\lambda = \int_0^1 \left[\mathbb{1}_{\{\lambda\leq\theta\}}(1-\delta) + \mathbb{1}_{\{\lambda>\theta\}}\frac{(1-\delta)h(\theta)}{\lambda}\right] d\lambda. \tag{52}$$

This implies that

$$\delta^* = \frac{h(\theta)\log(\theta)}{h(\theta)\log(\theta)-\theta}, \tag{53}$$

which can be increasing in θ, as summarized in the next proposition.

Proposition 12. (Liquidity Reserves and Financial Fragility) *Whenever*

$$h'(\theta) > \frac{h(\theta)+h(\theta)|\log\theta|}{\theta|\log\theta|}, \tag{54}$$

an increase in reserves θ causes an increase in financial fragility δ^*, or

$$\frac{\partial\delta^*}{\partial\theta} > 0. \tag{55}$$

The intuition is that an increase in reserves can increase the attractiveness of withdrawing early. To see this, consider the extreme case in which the warehouse holds no reserves or $\theta = 0$. In this case, a depositor never wishes to withdraw early because he never receives any grain, regardless of whether there is a run. Thus, having more reserves has an "incentive effect," in that it makes withdrawing more attractive for depositors. Note that, despite this incentive effect, increasing reserves does not increase

[35] See Goldstein and Pauzner (2005) for an application to bank runs and Morris and Shin (2003) for a survey.

[36] We gloss over the necessary conditions for global games techniques to apply here. For example, it must be that $\delta < 0$ and $\delta > 1$ with some probability, since to withdraw and not to withdraw must be dominant strategies for some parameters.

financial fragility for all parameters (as expressed in equation (54)). This is because, the usual "buffer effect," by which more reserves make the bank able to withstand more withdrawals, is still present. Which effect dominates is determined by the slope of the function h that captures the liquidation discount.

7 Conclusion

Summary of paper. In this paper we have developed a new theory of banking that is tied to the origins of banks as commodity warehouses. The *raison d'être* for banks does not require asymmetric information, screening, monitoring, or risk aversion. Rather, we show that the institutions with the best storage (warehousing) technology have an advantage in enforcing contracts, and are therefore not only natural deposit-takers but are also natural lenders—i.e. they are natural banks. With this theory we show how banks create liquidity even when they do *not* provide superior risk sharing. While most of the existing literature views bank liquidity creation as being synonymous with improved risk sharing for risk-averse depositors, we focus on ex ante *funding* liquidity creation, which is the bank-attributed increase in the initially available liquidity that can be channeled into aggregate investment in productive activities. The key to the bank's ability to do this is the issuance of "fake" warehouse receipts by the bank. This creates a striking contrast with the existing literature, which views the process of liquidity creation as banks accepting deposits that are then loaned out, i.e., deposits create loans. In our theory, loans also create deposits. We thus decouple the notion of creating liquidity from risk preferences and show that risk aversion is neither a sufficient nor necessary condition for ex ante liquidity creation. In this way, our analysis of bank liquidity creation *complements* the focus of the existing literature on the bank creating liquidity through better risk sharing.

Our theory has regulatory implications. It shows that proposals like narrow banking and liquidity requirements on banks will diminish bank liquidity creation and be inimical to economic growth. By contrast, higher levels of bank capital enhance bank liquidity creation. Moreover, we establish conditions under which a tighter monetary policy induces more liquidity creation.

Empirical implications. Our paper generates numerous predictions that could be tested. First, across countries, banks that provide warehousing services should play a more important role in countries with weaker property rights. Second, more aggregate funding liquidity will be created in the economy when banks have higher capital. Third, liquidity requirements on banks will reduce aggregate liquidity creation.

Future research. There are many possibilities for future research. One is to introduce a more meaningful role for the central bank as "the warehouse for warehouses", i.e., a bank that warehouses can deposit with. Additional frictions or incentive problems can then be introduced to generate regulatory policy implications. Another possibility is to create an environment in which it pays for the warehouse to screen potential borrowers and develop an expertise to do so. Interactions of screening with storage can then be examined.

Appendix

A Interbank Market

In this subsection we model the interbank market explicitly. We show that the assumption that a farmer deposits in the same warehouse it borrowed from is without loss of generality. We do this by expanding the model and showing the following results.

(i) If the interbank market is a perfect Walrasian market, then any equilibrium is pay-off equivalent to the one in which the farmer deposits in the warehouse he borrows from.

(ii) If there is any positive cost ε of switching warehouses, then the borrower strictly prefers to deposit in the warehouse he borrowed from. Thus, the equilibrium in which the farmer deposits in the warehouse he borrows from is unique. Further, this holds even if the interbank market is not a frictionless Walrasian market.

Interbank market setup. In this subsection we consider only Date 1. The farmer holds grain y and has debt $R^L B < y$ to one warehouse, which we refer to as Warehouse 0. The sequence of moves at Date 1 is then as follows. First, warehouses post deposit rates. Second, the farmer deposits in a warehouse or stores privately. Third, the farmer's debt is traded in the interbank market. Fourth, if a warehouse holds the farmer's debt and the farmer's grain, the warehouse seizes the grain that it is owed.

We refer to the price of a bond with face value one as p. Thus, $R^L B$ is the total supply of the farmer's debt. It is all initially held by Warehouse 0. We refer to a warehouse b's demand for the farmer's debt as x^b.

Before showing the results (i) and (ii) above, we note that the deposit rates must all be one, as we establish in Lemma 1. This follows from no-arbitrage arguments. In particular, if a warehouse sets a rate greater than one to try to attract the farmer, it would receive an infinite inflow of deposits.

(i) Frictionless interbank market. If the farmer deposits in Warehouse 0, then Warehouse 0 seizes the amount $R^L B$ that it is owed. There is no trade in the interbank market. The farmer's payoff is $y - R^L B$.

Now suppose that the farmer deposits y in any other warehouse, which we refer to as Warehouse 1. Now, Warehouse 0 holds the farmer's debt but does not hold the farmer's grain and therefore cannot seize it. Warehouse 1 holds the farmer's grain but does not hold the farmer's debt and therefore does not have the right to seize the grain it holds. However, there is trade in the interbank market at price p. The key to the argument in this section is that the price p must be one for the market to clear. This implies that Warehouse 0 is effectively repaid in full, since it sells the farmer's debt for $pR^LB = R^LB$, the same amount it would seize if the farmer deposited with it directly.

LEMMA 7. *The price of the farmer's bonds in the interbank market is one, $p = 1$.*

The key insight in the proof is that, because Warehouse 1 can seize debt at par, the debt cannot trade at a discount from par—if the price is less than one, then Warehouse 1 demands more than the total supply. We now show this formally.

Proof. The proof is by contradiction.

First suppose (in anticipation of a contradiction) that $p < 1$. Warehouse 1, who holds the farmer's grain, demands $x^1 = y$. This is greater than the total supply of the farmer's debt, $R^LB < y$. Thus, the market cannot clear. We conclude that it must be that $p \geq 1$.

Now suppose (in anticipation of a contradiction) that $p > 1$. Warehouse 0 sells all of the farmer's debt, supplying R^LB, but no warehouse buys the farmer's debt, since the price is greater than any warehouse's private value. Thus, the market cannot clear. We conclude that it must be that $p \leq 1$. Since $p \geq 1$ and $p \leq 1$, $p = 1$. □

We now conclude the analysis of the farmer's repayment. Trade in the interbank market results in Warehouse 1 buying all R^LB units of the farmer's debt at price $p = 1$. Warehouse 1 seizes R^LB units of the farmer's grain. Thus, the outcome is the same as if the farmer deposited in Warehouse 0 directly: Warehouse 0 receives $pR^LB = R^LB$. Warehouse 1 pays $pR^LB = R^LB$ for the farmer's debt, which is worth exactly R^LB to it. The farmer repays its debt.

(ii) Switching costs. Now suppose that the farmer must pay a cost $\varepsilon > 0$ to switch warehouses—i.e. to deposit with a warehouse different from the one he borrowed from. ε may be arbitrarily small and might represent the cost of travel or transport to a new warehouse or the administrative cost of opening an account. Given there is a Walrasian interbank market, it follows immediately from the analysis above that the farmer strictly prefers to deposit in Warehouse 0. In this case, the unique equilibrium is that in which the farmer deposits in the same warehouse he borrowed from.

Note that this is the unique equilibrium even if there is not a Walrasian market. To see this, suppose that when the farmer deposits in Warehouse 1, the warehouse can buy (all of) the farmer's debt for pR^LB, where $p \in (0, 1)$. This price could be the outcome of bilateral bargaining, for example, rather than a Walrasian auction. This is a profitable trade for the warehouses. As a result, Warehouse 1 acquires the farmer's debt and seizes his deposits; thus the farmer ends up repaying in full. But he has also paid the switching cost ε. Thus, it is strictly better to deposit in Warehouse 0 directly.

This analysis shows that the interbank market works to ensure the farmer repays his debt to his creditor even if there are frictions in the interbank market, i.e. even if prices in the interbank market differ from the Walrasian market-clearing prices. This finding contrasts with the results in Broner, Martin and Ventura (2010). In that paper, frictionless markets are necessary to ensure investors get repaid, specifically "[w]hatever assets exist, it should be possible to retrade them in secondary markets that are competitive and free from government intervention and other trading frictions" (p. 1524).

B Proofs

Proof of Proposition 1

As discussed in the text preceding the statement of the proposition, in the first best all grain is invested in its first-best use at Date 0. This corresponds to $i_{\text{fb}} = e$, since the farmer's technology is the most productive. The production function requires $\ell_{\text{fb}} = \alpha i = \alpha e$ units of labor to be productive, and any more is unproductive. In summary, $i_{\text{fb}} = e$ and $\ell_{\text{fb}} = \alpha e$, as stated in the proposition. □

Proof of Proposition 2

In this proof we make use of the results in Subsection 4.2.1 that state the prices and of Lemma 5 that simplifies the problem of solving for the equilibrium. Note that although these results come after this proposition in the text, they do not depend on it. Thus, we may employ them in this proof.

The equilibrium allocation again solves the farmer's problem, but in this case the warehouse cannot issue more receipts than has deposits so $s_0^b \geq 0$. Further, since the warehouse has no endowment, its budget constraint reads $L + s_0^b = D_0$. Thus, $L = 0$. Market clearing implies $B = 0$. The farmer's problem is thus to

$$\text{maximize} \quad d_1^f \tag{A.1}$$

subject to

$$d_1^f = A \max\left\{\alpha i, \ell^f\right\}, \tag{A.2}$$

$$i + \ell^f = e. \tag{A.3}$$

The solution to the problem is

$$\ell_{\text{nr}} = \frac{\alpha e}{1+\alpha}, \tag{A.4}$$

$$i_{\text{nr}} = \frac{e}{1+\alpha}, \tag{A.5}$$

as expressed in the proposition. $\square$

Proof of Lemma 1

We show the result by contradiction. If $R_t^D \neq 1$ in equilibrium, deposit markets cannot clear.

First suppose (in anticipation of a contradiction) that $R_t^D < 1$ in equilibrium (for either $t \in \{0, 1\}$). Now set $s_t^b = D_t$ in the warehouse's problem in Subsection 3.4. The warehouse's objective function (equation (8)) goes to infinity as $D_t \to \infty$ without violating the constraints. The deposit markets therefore cannot clear if $R_t < 1$, a contradiction. We conclude that $R_t^D \geq 1$.

Now suppose (in anticipation of a contradiction) that $R_t^D > 1$ in equilibrium (for either $t \in \{0, 1\}$). Now set $s_t^b = D_t$ in the warehouses problem. The warehouse's objective function goes to infinity as $D_t \to -\infty$ without violating the budget constraints. Thus, if $R_t^D > 1$, it must be that $D_t = 0$. However, since the depreciation rate $\delta > 0$, the demand from laborers and farmers to store grain is strictly positive for $R_t^D > 1 - \delta$. Thus, again, deposit markets cannot clear, a contradiction. We conclude that $R_t^D \leq 1$.

The two contradictions above taken together imply that $R_t^D = 1$ for $t \in \{0, 1\}$. $\square$

Proof of Lemma 2

We show the result by contradiction. If $R^L \neq 1$ in equilibrium, loan markets cannot clear.

First suppose (in anticipation of a contradiction) that $R^L > 1$ in equilibrium. Now set $L = D_t$ in the warehouse's problem in Subsection 3.4. Given that $R_0^D = 1$ from Lemma 1 above, the warehouse's objective function (equation 8) goes to infinity as $L \to \infty$ without violating the constraints. The deposit markets therefore cannot clear if $R^L > 0$, a contradiction. We conclude that $R^L \leq 1$.

Now suppose (in anticipation of a contradiction) that $R^L < 1$ in equilibrium. Now set $L = D_0$ in the warehouse's problem. Given that $R_0^D = 1$ from Lemma 1 above, the warehouse's objective function goes to infinity as $L \to -\infty$ without violating the budget constraints. Thus, if $R^L < 1$, it must be that $D_0 = 0$. However, since the depreciation rate $\delta > 0$, the demand from laborers and farmers to store grain is always strictly positive for $R_t^D > 1 - \delta$. Thus, again, deposit markets cannot clear, a contradiction. We conclude that $R^L \geq 1$.

The two contradictions above taken together imply that $R^L = 1$. $\square$

Proof of Corollary 1

Given Lemma 1 above, the result is immediate from inspection of the farmer's problem and the laborer's problem in Subsection 3.4 given that $R_0^D = R_1^D = 1 > 1 - \delta$, the return from private storage. $\square$

Proof of Lemma 3

We show the result by contradiction. If $w \neq 1$ in equilibrium, labor markets cannot clear.

First suppose (in anticipation of a contradiction) that $w > 1$ in equilibrium. From Corollary 1, $d_0^l = w\ell^l$ and $d_1^l = R_0^D d_0^l$ in the laborer's problem in Subsection 3.4. The constraints collapse, and the laborer's objective function (equation (10)) is $R_1^D R_0^D w\ell^l - \ell^l = (w-1)\ell^l$, having substituted $R_0^D = R_1^D = 1$ from Lemma 1 above. Since $w > 1$ by supposition, the objective function approaches infinity as $\ell^l \to \infty$ without violating the constraints. The labor market therefore cannot clear if $w > 1$, a contradiction. We conclude that $w \leq 1$.

Now suppose (in anticipation of a contradiction) that $w < 1$ in equilibrium. As above, the laborer's objective function is $(w-1)\ell^l$. Since $w < 1$ by supposition, the laborer sets $\ell^l = 0$. The farmer, however, always has a strictly positive demand for labor if $w < 1$—he produces nothing without labor and his productivity $A > 1 + 1/\alpha$ by Parameter Restriction 1. The labor market therefore cannot clear if $w < 1$, a contradiction. We conclude that $w \geq 1$.

The two contradictions above taken together imply that $w = 1$. $\square$

Proof of Lemma 4

The result follows immediately from the proofs of Lemma 1, Lemma 2, and Lemma 3, which pin down the prices in the model by demonstrating that if prices do not make these players indifferent, markets cannot clear, contradicting that the economy is in equilibrium. $\square$

Proof of Lemma 5

The result follows from Lemma 4 and substituting in prices and demands from the preliminary results in Subsection 4.2.1. In short, since, given the equilibrium prices, laborers and warehouses are indifferent among allocations, they will take on the excess demand left by the farmers to clear the market. $\square$

Proof of Proposition 3

We begin by rewriting the farmer's problem in Lemma 5 as

$$\text{maximize} \;\; d_1^f \tag{A.6}$$

subject to

$$\delta\Big(A\max\left\{\alpha i, \ell^f\right\} + d_0^f\Big) \geq B, \tag{IC}$$

$$d_1^f + B = A\max\left\{\alpha i, \ell^f\right\} + d_0^f, \tag{BC$_1^f$}$$

$$d_0^f + i + \ell^f = e + B, \tag{BC$_0^f$}$$

and $i \geq 0, \ell^f \geq 0, B \geq 0, d_0^f \geq 0$, and $d_1^f \geq 0$.

Now observe that at the optimum, $\max\left\{\alpha i, \ell^f\right\} = \ell^f$ and $\ell^f = \alpha i$. Further, eliminate the d_1^f in the objective from the budget constraint. Now we can write the problem as

$$\text{maximize} \;\; A\ell^f + d_0^f - B \tag{A.7}$$

subject to

$$\delta\Big(A\ell^f + d_0^f\Big) \geq B, \tag{IC}$$

$$d_0^f + i + \ell^f = e + B, \tag{BC$_0^f$}$$

$$\ell^f = \alpha i \tag{A.8}$$

and $i \geq 0, \ell^f \geq 0, B \geq 0$, and $d_0^f \geq 0$.

We see that the budget constraint and $\ell^f = \alpha i$ imply that

$$B = d_0^f + \frac{1+\alpha}{\alpha}\ell^f - e \tag{A.9}$$

and, thus, the objective is

$$A\ell^f - \frac{1+\alpha}{\alpha}\ell^f + e = \frac{\alpha(A-1)-1}{\alpha}\ell^f + e. \tag{A.10}$$

This is increasing in ℓ^f by Parameter Restriction 1, so ℓ^f is maximal at the optimum. Thus, the incentive constraint binds, or

$$\delta\big(A\ell^f + d_0^f\big) = B = d_0^f + \frac{1+\alpha}{\alpha}\ell^f - e. \tag{A.11}$$

or

$$e - (1-\delta)d_0^f = \left(1 - \delta A + \frac{1}{\alpha}\right)\ell^f. \tag{A.12}$$

Since, by Parameter Restriction 2, $\delta A < 1$, setting $d_0^f = 0$ maximizes ℓ^f. Hence,

$$\ell^f = \frac{\alpha e}{1 + \alpha\big(1 - \delta A\big)}. \tag{A.13}$$

Combining this with the budget constraint and the equation $i = \ell^f/\alpha$ gives the expressions in the proposition. □

Proof of Proposition 4

The result follows immediately from comparison of the equilibrium expression for $i + w\ell$ given in Proposition 3 with the expression for $i_{\text{nr}} + w\ell_{\text{nr}}$ given in Proposition 2. Note that $w = 1$ in the benchmark with no receipts as well as in the full model. The proofs of the results for the prices (in particular for the wage w) in Subsection 4.2.1 are unchanged for the benchmark. □

Proof of Corollary 2

The result follows from direct calculation given the equilibrium expressions for Λ, D_0 and s_0^b. □

Proof of Corollary 3

The result is immediate from differentiation, as expressed in equation (27). □

Proof of Proposition 5

The expression given in the proposition is positive as long as $1 - \delta A > 0$. This holds by Parameter Restriction 2. The result follows immediately. □

Proof of Proposition 6

The liquidity ratio inhibits liquidity creation whenever warehouses' equilibrium Date 0 grain holdings s_0^b are insufficient to satisfy their liquidity requirements. In other words, given equation (31), if

$$B < \frac{1-\theta}{\theta} s_0^b, \tag{A.14}$$

then liquidity requirements inhibit liquidity creation. Given the equilibrium values of s_0^b and B, this can be rewritten as

$$\frac{\delta A \alpha e}{1 + \alpha\big(1 - \delta A\big)} < \frac{1-\theta}{\theta} \frac{\alpha\big(1 - \delta A\big)e}{1 + \alpha\big(1 - \delta A\big)}. \tag{A.15}$$

This holds only if

$$\theta < 1 - \delta A. \tag{A.16}$$

Whenever this inequality is violated, liquidity requirements inhibit liquidity creation. It is the negation of the above equality stated in the proposition. □

Proof of Proposition 8

The proof comes for solving for the Date-1 deposits D_1 in the second-best equilibrium and checking when the warehouse's incentive constraint (equation (34)) is violated. In the second-best equilibrium we have that

$$D_1 = y + s_0^b \tag{A.17}$$

$$= A\alpha i + (e - i) \tag{A.18}$$

$$= \frac{\alpha\big[1 + (1-\delta)A\big]e}{1 + \alpha(1 - \delta A)}, \tag{A.19}$$

having substituted for i from the expression in Proposition 3. Thus, the warehouse's IC is violated for $e^b < \hat{e}^b$, where $\hat{e}^b$ solves

$$\frac{1-\delta}{\delta} = \frac{\hat{e}^b}{D_1} = \frac{\big[1 + \alpha(1 - \delta A)\big]\hat{e}^b}{\alpha\big[1 + (1-\delta)A\big]e} \tag{A.20}$$

or

$$\hat{e}^b = \frac{1-\delta}{\delta}\frac{\alpha\big[1 + (1-\delta)A\big]}{1 + \alpha(1 - \delta A)}e. \tag{A.21}$$

Proof of Proposition 9

This result follows from solving for the equilibrium with the warehouse's incentive constraint binding. We proceed assuming that lending L is positive. If it is negative, the formulae do not apply and $L = 0$.

Begin with the warehouses' binding incentive constraint, which gives a formula for D_1, the total grain deposited at Date 1,

$$D_1 = \frac{\delta}{1-\delta}e^b. \tag{A.22}$$

The Date-1 deposit market clearing condition implies that the total amount of deposits equals the total amount of grain at Date 1. This is the sum of the farmer's output y

and the grain stored in the warehouse at Date 0, s_0^b,

$$D_1 = y + s_0^b \tag{A.23}$$

$$= A\alpha i + e - i. \tag{A.24}$$

Combining this with the warehouses' incentive constraint gives

$$i = \frac{1}{\alpha A - 1}\left(\frac{\delta}{1-\delta}e^b - e\right). \tag{A.25}$$

(Note that $\alpha A - 1 > 0$ by Parameter Restriction 1.) Now, since the farmers' technology is Leontief, $\ell = \alpha i$. This allows us to write the expression for the liquidity multiplier Λ:

$$\Lambda = \frac{i + w\ell}{e} \tag{A.26}$$

$$= \frac{1+\alpha}{\alpha A - 1}\left(\frac{\delta}{1-\delta}\frac{e^b}{e} - 1\right). \tag{A.27}$$

This expression applies when it is greater than one (and e^b is below the threshold in Proposition 8) or

$$\frac{1+\alpha}{\alpha A - 1}\left(\frac{\delta}{1-\delta}\frac{e^b}{e} - 1\right) \geq 1. \tag{A.28}$$

Which can be rewritten as

$$e^b \geq \frac{\alpha(1-\delta)(1+A)e}{(1+\alpha)\delta} =: \hat{\hat{e}}^b. \tag{A.29}$$

Otherwise, no liquidity is created and the liquidity multiplier is one. □

Proof of Lemma 6

The proofs that $R_0^D = R_1^D = R^L = R^{\mathrm{CB}}$ are all identical to the proofs of the analogous results in Subsection 4.2.1 with the warehouses' return on storage (which is one in the baseline model) replaced with the central bank rate R^{CB}. The result is simply that warehouses lend and borrow at their cost of storage, which is a result of warehouses being competitive.

The result that $w = \left(R^{\mathrm{CB}}\right)^{-2}$ is also nearly the same as the proof of the analogous result (Lemma 3) in Subsection 4.2.1. The modification is that the laborer's objective function (equation (10)) reduces to $c^l = \left(R^{\mathrm{CB}}\right)^2 w\ell - \ell$, since the laborer invests its income in the warehouse for two periods at gross rate R^{CB}. In order for the laborer not to supply infinite (positive or negative) labor ℓ, it must be that $w = \left(R^{\mathrm{CB}}\right)^{-2}$. □

Proof of Proposition 10

Solving for the equilibrium again reduces to solving the farmer's problem with binding incentive and budget constraints. With the prices given in Lemma 6 these equations are

$$R^{\mathrm{CB}}\left(y-R^{\mathrm{CB}}\right)=(1-\delta)y \tag{A.30}$$

and

$$i+\left(R^{\mathrm{CB}}\right)^{-2}\ell=e+B \tag{A.31}$$

where $y=A\max\{\alpha i,\ell\}$ and, in equilibrium, $i=\alpha\ell$. From the budget constraint we find that

$$\ell=\frac{\alpha\left(R^{\mathrm{CB}}\right)^{2}(e+B)}{\alpha+\left(R^{\mathrm{CB}}\right)^{2}} \tag{A.32}$$

and, combining the above with the incentive constraint,

$$B=\frac{\alpha A\left(R^{\mathrm{CB}}-1+\delta\right)e}{\alpha+\left(R^{\mathrm{CB}}\right)^{2}-\alpha A\left(R^{\mathrm{CB}}-1+\delta\right)}. \tag{A.33}$$

This gives the following equilibrium allocation:

$$\ell=\frac{\alpha\left(R^{\mathrm{CB}}\right)^{2}e}{\alpha+\left(R^{\mathrm{CB}}\right)^{2}-\alpha A\left(R^{\mathrm{CB}}-1+\delta\right)}, \tag{A.34}$$

$$i=\frac{\left(R^{\mathrm{CB}}\right)^{2}e}{\alpha+\left(R^{\mathrm{CB}}\right)^{2}-\alpha A\left(R^{\mathrm{CB}}-1+\delta\right)}. \tag{A.35}$$

We use the allocation to write down the liquidity multiplier Λ as

$$\Lambda=\frac{i+w\ell}{e} \tag{A.36}$$

$$=\frac{\alpha+\left(R^{\mathrm{CB}}\right)^{2}}{\alpha+\left(R^{\mathrm{CB}}\right)^{2}-\alpha A\left(R^{\mathrm{CB}}-1+\delta\right)}. \tag{A.37}$$

We now compute the derivative of Λ with respect to R^{CB} to show when increasing R^{CB} increases Λ:

$$\begin{aligned}\frac{\partial\Lambda}{\partial R^{\mathrm{CB}}}&=\frac{2R^{\mathrm{CB}}\left[\alpha+\left(R^{\mathrm{CB}}\right)^{2}-\alpha A\left(R^{\mathrm{CB}}-1+\delta\right)\right]-\left(\left(R^{\mathrm{CB}}\right)^{2}+\alpha\right)\left(2R^{\mathrm{CB}}-\alpha A\right)}{\left[\alpha+\left(R^{\mathrm{CB}}\right)^{2}-\alpha A\left(R^{\mathrm{CB}}-1+\delta\right)\right]^{2}}\\&=\frac{\alpha A\left[\alpha+2(1-\delta)R^{\mathrm{CB}}-\left(R^{\mathrm{CB}}\right)^{2}\right]}{\left[\alpha+\left(R^{\mathrm{CB}}\right)^{2}-\alpha A\left(R^{\mathrm{CB}}-1+\delta\right)\right]^{2}}.\end{aligned}$$

This is positive exactly when $\alpha+2R^{\mathrm{CB}}(1-\delta)>\left(R^{\mathrm{CB}}\right)^{2}$ as stated in the proposition. $\square$

C Table of Notations

	Indices
f	farmer index
l	laborer index
b	warehouse (bank) index
$t \in \{0, 1, 2\}$	time index
	Prices
R_t^D	deposit rate at Date t
R^L	lending rate at Date 0
w	wages at Date 0
	Demand and Supply
i	grain farmers invest at Date 0
ℓ^f	labor farmers demand at Date 0
ℓ^l	labor laborers supply at Date 0
s_t^j	grain stored by player j at Date t
d_t^f	grain deposited in warehouses by farmers at Date t
d_t^l	grain deposited in warehouses by laborers at Date t
B	loans demanded by farmers at Date 0
L	loans supplied by warehouses at Date 0
D_t	overall deposits in warehouse at Date t
	Production and Consumption
y	farmers' output at Date 1
c^j	consumption of player j at Date 2
	Parameters
δ	depreciation rate with private storage
A	productivity
α	ratio of labor to grain in farmers' production
e	farmers' (Date 0) endowment
e^b	warehouses' (Date 1) endowment (extension in Subsection 5.2)
$\hat{e}^b$, $\hat{\hat{e}}^b$	thresholds of warehouse capital determining lending behavior (extension in Subsection 5.2)
h	cost of liquidating grain at Date 0^+ (extension in Subsection 6.2)
	Other Variables
g_1^f	farmer's grain holding at Date 1
Λ	liquidity multiplier
θ	liquidity ratio (extension in Subsection 5.1)
R^{CB}	central bank rate (extension in Subsection 5.3)

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