An Integrated Framework for Analyzing Multiple Financial Regulations*

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In this companion paper to Goodhart et al. (2012), we explore the interactions of various types of financial regulation. We find that regulations that control fire-sale risk are critical for delivering financial stability and improving the welfare of savers and borrowers. We describe the combinations of capital regulations, margin requirements, liquidity regulation, and dynamic provisioning that are most effective in this respect. A policy featuring margin requirements together with countercyclical capital requirements delivers equal or better outcomes for the economy than does an unregulated financial system. But it is easy to produce combinations of regulation

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that look sensible but, when combined, have adverse effects on the economy.

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1. Introduction

Donald Kohn has a remarkable ability to not only attack problems using many approaches but also incorporate insights from a variety of perspectives in doing so. This flexibility was critical to the success of his leadership within the Federal Reserve during a period when both the economy and our understanding of the economy were constantly evolving. When his career began, the concept of "macroprudential financial regulation" did not exist. Instead, the United States and much of the developed world was saddled with a set of outdated regulations that contributed to macroeconomic instability in the 1970s. By the time Don retired from the Federal Reserve, the landscape of central banking had changed and the term "macroprudential" was part of the standard lexicon of central bankers. We share the Kohn (2011) view that "the consistent and systematic application of this [macroprudential] perspective to highly sophisticated globally integrated markets and institutions as is now being undertaken in the UK, US, and other advanced economies is in its infancy."

Kohn (2010) argued that policymakers should "use regulation and supervision to strengthen the financial system and lean against developing problems. Given our current state of knowledge, monetary policy would be used only if imbalances were building and regulatory policies were either unavailable or had been shown to be ineffective. But, of course, we should all be working to improve our state of knowledge, so as to better understand economic and financial behavior and to further expand the range of policy tools that can be employed to enhance macroeconomic performance."

In this paper we take up Don's challenge to explore the range of policy tools beyond the short-term interest rate that can be used to contribute to macroeconomic stability. Our starting point is the framework introduced in Goodhart et al. (2012) (henceforth GKTV 2012). That model was built to study an economy that is at risk of an occasional asset-price collapse. The novel feature of the model is the inclusion of both a traditional banking and a "shadow banking" system that each helps households finance their expenditures and smooth their consumption intertemporally. But if asset prices collapse, the consumers default and the financial system amplifies the default. The financial amplification creates a number of distortions.

In our initial paper we mostly concentrated on how a range of regulatory tools, used in isolation, could enhance stability. One of the main lessons from that exercise was that tools should be grouped according to the distortions that they addressed, rather than on the incidence of the regulation. For example, a loan-to-value regulation that reduces the leverage that a consumer can take on and margin requirements on repurchase agreements between banks and shadow banks share an important similarity. Both of these regulations limit the extent to which risks can build up ahead of an asset-price collapse by limiting credit availability. So even though their immediate effect is to constrain different agents in the economy from taking risks, in general equilibrium the price effects transmit the constraints across the entire economy. Therefore, in many respects these two tools are closer to being substitutes than complements because their first-order impact is to limit the buildup of risks. Other tools might slow an asset-price boom that is already under way or serve to strengthen the financial system after an asset-price collapse.

In this paper we explore the interactions between different tools much more comprehensively than in our earlier work. In particular, we focus on combining regulations to study their joint effects when they are simultaneously deployed. We find that controlling fire-sale risk is critical to improving overall economic performance. But not all strategies of controlling this risk are equally effective. The intuition for why some combinations work better than others is subtle and depends critically on the channels through which different tools operate. While this research program is still very early, we believe it is also already showing signs of the promise of pursuing the Kohn agenda of considering alternative tools for financial stability.

Section 2 of the paper briefly reviews the modeling philosophy that distinguishes our approach from the orthodox approach that prevailed prior to the financial crisis. Section 3 reviews the model in general terms, although for details the reader should consult GKTV (2012). Section 4 presents the baseline equilibrium in the economy and briefly shows how the equilibrium is altered by the five regulatory tools we consider in this paper. Section 5 provides the new contributions from this paper that relate to combination policies of the different tools, including some intuition that we believe is helpful for more general settings than those we are currently able to model. Section 6 concludes.

2. Modeling Philosophy

The ruling workhorse models used by central banks prior to the financial crisis that began in 2008 essentially ignored the financial system (see, for example, Woodford 2003). This was especially ironic since the four professional economists who were governors of the Federal Reserve System in 2007 (Bernanke, Kohn, Kroszner, and Mishkin) each gave at least one speech in 2007 emphasizing the risks that financial instability posed for the economy.[1] But the fact remains that most published papers on central banking and related courses in leading graduate programs did not share this view.

Subsequent to the crisis, the profession has scrambled to correct this problem. Nonetheless, we believe that most of the responses continue to carry the baggage that had built up prior to the crisis when financial factors were considered a sideshow. So before getting into the details of our approach, it is helpful to review the direction followed by most people working on these issues. The core question is how to model default.

The typical assumption in most models is that economic agents will always honor their contractual obligations in all cases. One reason for the "no-default" assumption is the argument that the appropriate design of contracts will include sanctions that diminish the incentives of debtors to default. Indeed, a large literature following Kiyotaki and Moore (1997) presumes that borrowers pledge a level of collateral that fully protects lenders even in the most adverse scenario. However, such exhaustive terms can impede more efficient levels of intertemporal smoothing and result in lower welfare. As shown in Dubey, Geanakoplos, and Shubik (2005), positive default in equilibrium can be welfare improving when asset markets are incomplete and economic agents cannot write comprehensive contracts.

[1]See, for example, Bernanke (2007), Kohn (2007), Kroszner (2007), and Mishkin (2007); in fact, most of them gave more than one speech on this topic.

The standard approach in the macroeconomics literature that includes monetary policy decisions and financial frictions began with Bernanke, Gertler, and Gilchrist (1999). In that setup, the fundamental financing problem comes because a borrower's net worth would be too low to permit repayment. So shocks to borrowers' net worth become a central driving factor in the economy. But financial intermediaries can hedge against (aggregate) default coming from the real sector and thus avoid losses.

Moreover, the easiest way to incorporate financial frictions into a macro model without elaborating on the structure of the financial system is to add an exogenous credit-risk premium into the expenditure function, à la Curdia and Woodford (2010). But the exogeneity of that credit-risk premium means that such an approach offers no guidance about the factors that cause financial crises.

Our analysis goes in a different direction by allowing for default by financial intermediaries themselves. This implies that defaults can directly interfere with the supply of credit. This raises a host of new distortions and potential scope for regulatory interventions. We think that satisfactory models for studying macroprudential regulation must include the possibility of credit supply shocks.

3. Model Structure

We analyze a specific parameterization of the GKTV (2012) model. The full notation (see table 4 in appendix 1) and model equations are given in appendices 1 and 2, but for a longer explanation of the details, see GKTV (2012). So what follows is a brief, intuitive summary of the model and its properties. The model describes a two-period endowment economy with two goods and heterogeneous agents. In the first period, households trade to rebalance their endowments. In the second period, a shock occurs which determines whether that period's endowments will be high or low. Households seek to smooth their consumption over time (and across goods).

One household type (R) is very well endowed with "housing," which is a durable good. A second household type is less well endowed with "potatoes," a non-durable. Some of the agents who are endowed with potatoes (P) live and consume in both periods, and others (F) enter the economy in the second period as first-time buyers and serve the role of supporting the demand for housing.[2]

The two types of households trade with each other using money as the stipulated means of exchange. The role of the financial system is to intermediate funds between borrowers and lenders. Most importantly, it supplies credit to support purchases and facilitate the intertemporal smoothing of consumption.

In the benchmark equilibrium that we study, the R households are relatively rich. For these households the combination of their endowment and their monetary holdings is sufficient to allow them to fully smooth their consumption (across potatoes and houses in each period and between periods). In contrast, the other households need access to the financial system to avoid having large swings in consumption. This asymmetry is important because it means that regulation will mostly not affect the welfare of the R households, because they can use other strategies besides relying on the financial system to achieve their goals. But the defensive response of the rich households to regulation can have potentially important effects for the other households.

The desire to study the potential effects of regulatory arbitrage leads us to allow for two types of financial institutions, a commercial bank (B) and a shadow bank (or equivalently a non-bank, N). Household R, being the natural lender, deposits some of the revenues from housing sales with a commercial bank, which extends credit to household P in order to accommodate its housing purchases in the initial period. Deposits are unsecured, while credit to household P takes the form of a mortgage contract with the houses bought pledged as collateral in the event of default. Mortgages mature at the end of the second period, while deposits are optimally withdrawn in the beginning of that period, thus creating a maturity mismatch and a need for liquidity by the commercial bank.

Apart from collecting deposits and extending mortgages, the commercial bank offers short-term loans to all households to facilitate their transactions in every period. Short-term loans are repaid at the end of the respective period and are free of credit risk. Bank

[2]If the first-time homebuyers were absent, then in the event of default, all the goods would wind up being repurchased by the same agents, in which case default is much less important than in real situations where defaulting agents do not merely get to reacquire any assets against which they had borrowed.

B faces a portfolio problem and can choose to securitize some of the mortgages it extended and package them in mortgage-backed securities (MBS). The shadow bank, having a higher appetite for risk, is the natural buyer of these securities. Securitization allows the commercial bank to extend more credit without compromising its liquidity position. In addition, the introduction of a new asset (the MBS) enhances the hedging opportunities of the commercial bank. N finances its MBS purchases with its own capital and a repo loan from the commercial bank. The purchased MBS are pledged as collateral in the event of default.

Notice that this formalization of the shadow banks system delivers two nice properties. First, the regulatory structure can play a role in governing the extent of securitization and hence the size of the shadow banking system (see Tucker 2010). In particular, differences in the risk weights associated with mortgages and MBS for purposes of bank capital assessments will be one factor that determines whether housing finance is provided by the banking system or the shadow banking system.[3] Moreover, in the event of default on the mortgages, the impaired MBS are at risk for flowing back onto the books of the banks. This was an important accelerant in the crisis, at least in the United States (Adrian and Shin 2009).

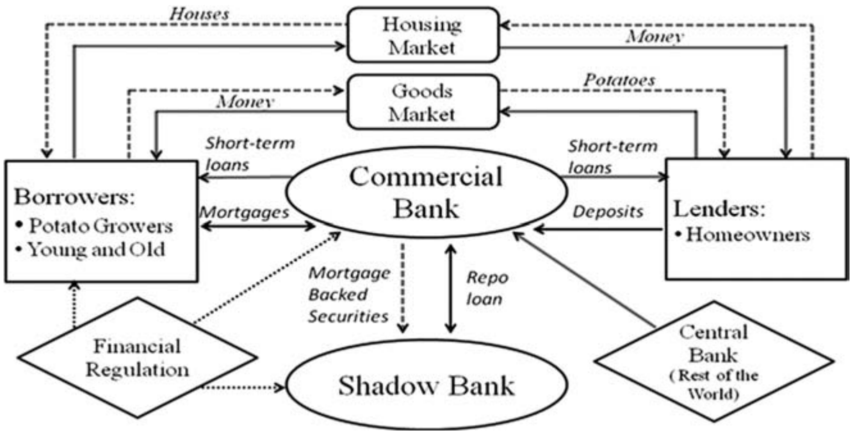
Finally, the bank funds its operations with its equity capital, deposits, and short-term borrowing (dubbed discount window loans) from the "central bank," which stands in for the rest of the world. The borrowing from the central bank is always limited to what can completely be repaid.

One important simplification is to assume that both the bank and non-bank are risk averse. If we assumed the financial institutions were risk neutral, then their willingness to take risk would lead to a number of extreme portfolio choices. We view the risk aversion as a shorthand way of modeling the many efficiency costs and managerial reputational costs that accompany a default and limit risk taking.

The decision to default is endogenous and depends on the relative value of collateral to the value of the loan obligation. Accounting for additional costs of default, such as reputational penalties, it is

[3]This is not the only reason why shadow banks exist. Even with identical capital charges for mortgages and MBS, their assumed differences in risk aversion create an incentive to securitize, and even with no differences in risk aversion, there would still be pure diversification benefits to sharing the housing risk.

Figure 1. Structure of the Economy



individually optimal for household P to default on its mortgage and have its house foreclosed when the market value of collateral is low enough. Similarly, the shadow bank may choose to return the MBS rather than repay the bank when the mortgages associated with the MBS are in default. As discussed below, the fall in housing prices and the subsequent defaults on mortgages create a number of secondary effects: fire sales, margin spirals, and a credit crunch. Financial regulation tries to mitigate the adverse effects of default due to a fall in asset/house prices. Regulation can be imposed either on the contributors to risk—i.e., household P and the shadow bank—or on the commercial bank, which by defaulting on deposits can amplify this risk.

Figure 1 presents the structure of the model, the financial relationships, and the flow of goods and houses in the real economy. We should note that this research program is just beginning and the modeling approach is very flexible. The general equilibrium setup with fully endogenous prices, portfolio decisions, and default allows for this. So this model is better thought of as a framework for comparing different potential financial externalities under various market structures. Hence the longer-term conclusions about regulatory design will depend on analyzing many variants of the model and determining which are robust to the many possible formalizations of the financial system.

To understand the model, it is helpful to realize that uncertainty primarily stems from whether the quantity of potatoes in period 2 is high or low relative to the amount of houses as well as monetary endowments and the central bank's lending rate.

When potatoes are abundant, then the borrowers from the first period can repay their loans and potentially even acquire more housing. So in this case there is no default and, instead, the financial institutions (and agents R and P who are also housing owners) experience capital gains on those assets. The only actor that suffers in this case are the new homebuyers, F, who face high home prices and have to compete to rent homes with others in the economy who are rebalancing their portfolios to reflect the capital gains.

The outcomes are much more subtle and complicated when the endowment of potatoes is low, because in this case house prices will collapse. This collapse is unavoidable, and default on mortgages is optimal from an individual's point of view. However, there are several channels through which the financial system may amplify the initial impulse that will lead to other inefficiencies. Regulations may be useful if they can limit this amplification.

The trigger for any amplification starts with the choice of the non-bank over whether to repay the repo loan or return the MBS which serve as collateral on the loan. Arbitrage guarantees that the effective return from buying MBS backed by defaulted mortgages must be the same as buying the underlying houses. So mortgage default must depress MBS prices. When the fall in housing prices is big enough, it becomes rational for N to suffer the reputational penalty associated with defaulting and return the collateral rather than repay the loan. In this case, the bank sees its asset values drop not only because of its losses on the mortgages that it retained but also because the MBS which it receives are worth less than the loan it was carrying on its books.

Given the asset impairment, B faces a decision over whether to default on its deposit obligations. In deciding whether to honor its deposit contracts, the bank trades off a reputational penalty associated with default against the profits that can be had from deploying the resources for other investments.

One alternative to defaulting is for the bank to sell assets to pay off the deposits. However, the only assets which can potentially be sold at the time when the deposits are due are the MBS that have been returned by the shadow banks. Depending on the availability of buyers to purchase MBS, selling assets may contribute to a fire sale.

We assume that MBS prices are subject to cash-in-the-market pricing (Allen and Gale 1994) whereby the value of the MBS is determined by the wealth of the potential buyers of the assets rather than the future cash flows generated by the assets. The shadow bank, which is the natural buyer of mortgage-backed securities, finds its capital depleted in the state of the world where housing prices collapse. Thus, given the limited resources of the shadow banks, the more MBS that the commercial bank returns to the market, the lower the price of MBS. This simple formulation is intended to capture the Shleifer and Vishny (2011) characterization of a fire sale whereby prices for assets are depressed because the natural buyers of the assets are impaired at the time of sale. Obviously, any regulation that limits the size of the initial repo default can potentially influence the size of the fire sale.

But the presence of the fire sale also creates three additional effects. The first comes because banks must make an active portfolio choice between holding onto their mortgage-backed securities and extending new loans. The bank is assumed to be unable to issue equity (in the immediate aftermath of the bad shock), so its balance sheet capacity is limited. Thus, the bank must trade off using its capital to hold a mortgage-backed security or to initiate new loans. So the losses on the MBS sales from the cash-in-the-market pricing tighten this capital constraint and potentially create a "credit crunch" for new borrowers (in that the bank's capital problem reduces the supply of loans that are available).

The second potential inefficiency comes because the repo default also raises the incentive for the bank to default on its deposit contracts. The losses to the depositor (R) reduce his wealth, causing him to sell additional housing to finance his purchases of goods. The additional housing sales will lead to lower housing prices.

Finally, there is a third channel that arises from the interaction of the cash-in-the-market fire sale and the other two additional effects. B always considers the arbitrage relation between MBS prices and the price of houses. When the bank receives the MBS that are issued against defaulted mortgages (from the shadow bank), it can either hold the MBS to maturity or sell the MBS right away, which depresses further not only MBS but also house prices. Therefore, the model also embodies the kind of downward spiral described in Brunnermeier and Pedersen (2009).

One prominent feature of the model is the asymmetry between the rich households and the other agents in the model. The combination of the risky deposit, money which can be used as a store of value, and the durable asset means that household R can invest in ways that protect itself from financial problems. But the way in which R responds to different risks or regulations will matter for the other agents. To take one particularly important example, depending on the extent of fire-sale risk, R will decide whether to retain some housing that can be sold in the second period (rather than saving through the banking system or with money). If R is selling more housing in the second period and the good state materializes, then the extent of the house appreciation in that scenario is limited (relative to the case where R is selling less). The relative price of housing is a key factor in determining whether P and F's welfare rises or falls. So even though R may be relatively immune to interventions that alter the financial system, R's response to these developments can be critical. This is why a full general equilibrium model is needed to study regulation and why partial equilibrium reasoning can be potentially misleading.

4. The Baseline Equilibrium and the Role of Financial Regulation

The remainder of our analysis proceeds using particular choices for the model parameters. The assumed values for endowments, wealth, financial institution's capital, central bank lending rates, default penalties, risk aversion, probabilities of good and bad states, discount rates, and housing depreciation rates are given in table 5 in appendix 1.

In reviewing the calibration, keep in mind that a period is presumed to be five years, so with the probability of the bad state being 10 percent, a crisis would be expected roughly every fifty years. We see the key choices in table 5 as relating to those that directly govern the size of the fire sale in the bad state. As we just explained, when the fire-sale risk is large, then financial sector amplification of the initial house-price decline is strong (and vice versa).

The two most important factors directly affecting the fire sale are the wealth of N (because that influences the degree of cash-in-the-market pricing) and the endowments of P and F, who are the homebuyers. The baseline version of the model (see table 6) is calibrated so that MBS prices fall by 26 percent in the crisis (and rise by 44 percent in the boom), so that the real-estate collapse is very much in line with the recent U.S. experience; the fire sale involves the bank selling only 6 percent of the MBS that it receives back as collateral.

In a crisis, households default on mortgages by only repaying forty-five cents on each dollar borrowed. The downpayment that they make is assumed to be 37 percent of the mortgage. The bank's willingness to permit the household to have more leverage is tempered by the bank's own risk aversion. One direction for future work is to explore the effects of presuming more willingness to take risks by the banks and non-banks. The banks in this calibration repay sixty cents on every dollar of deposits.[4]

Before exploring the effects of regulation on the equilibrium, it is helpful to note the channels through which regulation can improve the welfare of the households and financial institutions. Cataloging the various channels makes it easier to see the distributional effects of different policies.

R's welfare is almost immune to regulatory interventions, as he can undo almost all adverse effects by reoptimizing his mix of deposits and housing sales. However, as demonstrated above, his actions create pecuniary externalities through relative prices on P and F because they do not face complete markets. As a rule, he will save more through the banking system when defaults are less severe. But the attractiveness of retaining housing and selling the extra housing also depends on the size of the fire sale and the house-price collapse in the bad state. In order for a policy to make R definitely worse off, it must effectively reduce his wealth by making his endowment less valuable by changing the relative price of potatoes and houses; otherwise, he can adjust his savings strategy to evade the effects—we will see that there are regulations that can operate this way.

[4]The repayment rate can also be thought of as the expected probability of default when the decision to default is endogenous and there is no repayment on deposits in the event of default.

P can gain if he can get more housing in period 1 or 2 (or if in a crisis he defaults less). He can increase his first-period housing if more short-term lending in period 1 becomes available or more mortgage lending in period 1 is available. He can acquire more housing in the good state in period 2 if its relative price is lower because R is selling more, or if short-term lending terms are better.

F's gains depend solely on the period 2 relative price of potatoes to houses. In the good state, he can get more housing if potato prices are high, either because R is selling more housing or if short-term lending terms are better so that the same amount of potatoes can support a higher housing purchase. In the bad state, if the relative price of housing is lower, then he can buy more of it.

The financial institution payoffs depend on their profits and the size of their defaults. B gains in the good state when it makes more capital gains on the mortgages that it holds on the balance sheet. So, ceteris paribus, this can happen if it retains more mortgages or if it sees a bigger price appreciation on houses. Its welfare in the bad state depends on the size of its default. It also has higher profits whenever the spread between its lending rate and its cost of funding is higher (in either period 1 or 2).

Finally, the shadow bank gains in the good state when it makes more capital gains on its MBS holdings. These gains come from being able to hold more MBS or from larger house-price appreciation. In the bad state, the non-bank suffers based on the size of its default.

With these mechanisms in mind, we explore the potential effects of five regulatory tools: limits on loan-to-value ratios, capital requirements for banks, liquidity coverage ratios for banks, dynamic loan loss provisioning for banks, and margin requirements on repurchase agreements used by shadow banks. The point of each of the regulations is to limit the consequences of the housing-price collapse. Each of these interventions will limit fire sales in the bad state by reducing either the size of the non-bank's default on its repo loan or the size of the bank deposit default.

But because they differ in ways of inducing this stability, the effects can differ across agents. In particular, margin requirements, liquidity requirements, loan-to-value, and initial capital requirements all directly reduce mortgage lending in period 1. They differ in whether their incidence limits bank or non-bank lending more. The capital requirements in period 2 guarantee that banks are healthier after a default occurs to reduce directly the costs of the

Table 1. Impact of Alternative Regulations on Key Endogenous Variables (change relative to baseline equilibrium)

	LTV	MR	CR_1	CR_{2b}	LCR_1	DP
Securitization	−	−	+	+	+	+
Relative Price of Potatoes to Housing-Good State	−	≈0	≈0	+	+	+
Profits of the Bank Period 1	+	+	+	−	−	−
Profits of Bank Good State	+	+	−	−	−	−

Note: + indicates increase, − indicates decrease, ≈0 indicates no change.

default; the equilibrium adjustments, though, involve large lending changes in period 1. Dynamic provisioning damps the credit boom in the good state and thus only indirectly influences the fallout from a house price drop. The precise mathematical formulas for the regulatory ratios are given in appendix 3. In the text we focus on the key prices and quantities that govern welfare for the households and financial institutions.

Loan-to-value (LTV) requirements force households to use more of their own wealth to obtain a mortgage loan. The effects on the key endogenous variables in the model are shown in table 1. This regulation is unique among those we consider because it directly acts on P to limit his ability to obtain credit, rather than creating incentives for the bank or non-bank to extend less credit. Because the bank is risk averse, it will prefer smoother profit streams to more variable ones, so given that P will be able to obtain less total credit, B will spread this reduction over both the first and second period. Since the households endowed with potatoes are the primary borrowers in the economy, this credit contraction forces them to sell more potatoes, which lowers the price of potatoes relative to houses in both periods.

The impact on the different agents is shown in table 2. Given the reduction in relative price of potatoes, both P and F suffer from increasing the downpayment requirements on houses. The higher relative prices of houses deliver slightly higher capital gains on mortgages and MBS for the financial institutions in the good state. But more importantly, the lower loan-to-value ratio makes the homeowner absorb more of the losses from a housing-price collapse, so

Table 2. Impact of Alternative Regulations on Household Utilities and Financial Institutions' Welfare (change relative to baseline equilibrium)

	LTV	MR	CR_1	CR_{2b}	LCR_1	DP
P's Utility	−	≈0	+	+	+	+
F's Utility	−	≈0	≈ 0	+	+	+
R's Utility	≈0	≈0	≈0	≈0	−	−
B's Payoff	+	+	+	−	−	−
N's Payoff	+	+	≈0	−	≈0	−

Note: + indicates increase, − indicates decrease, ≈0 indicates no change.

that the financial institutions' defaults are much lower than without the loan-to-value regulation.

Margin requirements force non-banks to pledge more equity to secure their repo loans. This reduces the attractiveness of securitization so that relatively more of the housing financing that occurs comes via mortgages that remain on the balance sheets of the banks. These changes in the structure of financing benefit the banks in two ways. First, by virtue of a higher market share in housing financing, the banks capture more of the gains from the house-price appreciation in boom scenario. Second, the non-banks' higher equity contribution reduces the size of their repo default. As calibrated, this effect is strong enough to make N better off overall (and it also helps the bank). Households are essentially unaffected by the imposition of margin requirements: the relative price of houses is not much affected, and while P has a smaller default, that is because he was able to acquire less housing in period 1.

Capital ratios for banks in the baseline equilibrium are higher in period 1 than in the bad state.[5] The starting capital positions, therefore, are countercyclical. So care must be taken in thinking about which comparative static exercise to consider: a local perturbation to either the first-period ratio or ratio in the bad state will mean that the countercyclical rule would still be in place. Alternatively, one can examine a large-enough change in the capital requirement

[5]In the good state all assets are essentially riskless, so capital ratios are technically infinite.

in the bad state so that it becomes equal to the level observed in the initial period. We first describe the local experiments and explore combined changes in the last section of the paper.

Raising the capital requirement in period 1 induces the bank to hold fewer mortgages on its balance sheet. It substitutes by securitizing more of the mortgages it originates and by making more short-term loans in period 1. This portfolio shift generates slightly more profits in period 1 and fewer profits in the good state. But the bank's default is much lower in the bad state, which makes B better off. Because P is able to obtain less mortgage credit, his default is less severe, so he also is better off. As usual, R is essentially unaffected. The relative prices of houses and potatoes are not altered enough to change the outcomes for F. The non-bank becomes riskier by virtue of the additional MBS that it is holding: this generates additional profits in the good state and additional defaults in the bad state. On net, N's welfare is about the same.

Raising capital requirements in the bad state triggers several general equilibrium responses. First, the bank does less mortgage lending in period 1 to avoid losses in period 2. The bank's reduction in mortgage financing means that the bank also needs fewer deposits, so that R saves more using his housing endowment. This leads R to sell more houses in period 2, raising the relative price of potatoes in both states, making both P and F better off. The lower relative price of houses in the good state, and the lower overall reduction in first-period mortgages, means N is worse off. B suffers for these reasons (and also because its profits are lower in period 1) but does default by less when house prices crash. The net effect is still negative for the bank.

Liquidity requirements can also be applied in the first period or during the second period. Imposing liquidity requirements in the bad state leads to a massive fire sale because the only way for the bank to obtain liquidity is to sell its MBS. So this regulation makes no sense to consider.[6] Imposing liquidity requirements during the good state runs into the same problem as imposing capital requirements during booms. When asset prices are high, many assets can be easily

[6]We conjecture that this intuition about the danger of imposing a common liquidity requirement all the way through a credit cycle will carry over to other versions of the model.

sold. So to make this ratio bind, the regulation would have to be extremely aggressive, changing substantially as a boom developed. Since we do not view this as plausible, we also do not consider this regulation.

These considerations leave a first-period liquidity requirement for analysis. Banks meet this kind of liquidity requirement by making more short-term loans in period 1 and by securitizing the mortgages they do make—notice the similarity to the period 1 choices that are made by banks when they are faced with an ex post capital requirement. The bank sees profits fall in period 1 and the good state, and it is not better protected against default in the bad state. So the bank sees its payoffs reduced. The non-bank (just as with the initial capital requirement) sees its risk rise due to the additional securitization, but on net its overall payoff is not much affected. Because it has reduced mortgage issuance, the bank also reduces its deposit taking, which pushes R to do more saving using its housing endowment. The additional housing sales in the second period make F and P better off; P also benefits from defaulting less due to having less housing credit. R's utility drops very slightly because the housing sales in the good state are so large that they create a big decline in the relative price of houses, reducing his purchasing power.

Finally, it is possible to use dynamic provisioning, which we formalize as a direct tax on increasing real-estate-related lending in the good state. This makes it very different from the other tools in two respects. First, it is the only one of the regulatory options that is targeted directly at leaning against the credit boom. Second, it is the only regulation that by construction must impair R. Normally R has portfolio substitution possibilities involving shifting savings between deposits and housing that allow him to sidestep regulation. But by making real-estate lending more expensive in the good state, dynamic provisioning acts as a tax on R's endowment and forces him to sell more houses at a lower price. This leaves R worse off and P and F better off. Because the bank and non-bank both make much lower capital gains in the good state, their profits suffer as well.

5. Combined Regulations

The foregoing results suggest combinations of regulation that should work well together and those that would not be expected to interact well. We proceed under the assumption that the goal of financial regulation is to increase stability and credit availability so that both the financial institutions and the households are better off relative to the unregulated equilibrium. As a practical matter, we have seen that R's utility is very insensitive to regulation, so we concentrate on the other agents.

From table 2 we can see that certain tools are likely to be more effective than others. In particular, both margin requirements and loan-to-value regulations increase financial stability by making defaults less traumatic, and in doing so make the payoffs to the financial institutions higher than in the absence of regulation. But loan-to-value regulation depresses credit supply, making borrowers worse off, while margin requirements are much less restrictive. So it appears easier to find a bundle that makes everyone better off when margin requirements are used instead of requiring larger downpayments.

Likewise, raising capital requirements in the bad state and dynamic provisioning each reduce the relative price of houses in the good state. This benefits P and F at the expense of the financial institutions. But dynamic provisioning operates as a tax on R, while the capital requirements do not. So using ex post capital requirements should be more attractive than using our depiction of provisioning.

Capital requirements and liquidity requirements in the initial period are similar in that both reduce mortgage extensions and prevent P from defaulting as much in the bust. Capital requirements reduce the bank's default as well, while a liquidity requirement does not. In contrast, a higher liquidity ratio raises the relative price of potatoes in the good state, which benefits F.

Taken together, these observations suggest that combinations of regulation involving margins, capital ratios, and the initial liquidity ratio are the most promising to explore. The same reasoning suggests that substituting LTV requirements for margin requirements should deliver worse outcomes. Table 3 shows the change in welfare relative to the baseline from different regulatory packages of this sort. The three-way combinations dominate the two-way versions, so to limit the possibilities we concentrate on these.

The column 1 combination includes margins and the two capital ratios. When all three are in place, R's utility is equivalent to that of the baseline and the other agents are better off. The regulations interact in interesting ways. In particular, raising capital requirements in period 1 leads to a carryover of capital into the second

Table 3. Impact of Combining Regulations on Household Utilities and Financial Institutions' Welfare (change relative baseline equilibrium)

	CR_1 & CR_{2b} & MR	CR_1 & LCR_1 & MR	CR_1 & CR_{2b} & LTV
P's Utility	+	+	≈0
F's Utility	+	−	−
R's Utility	≈0	≈0	≈0
B's Payoff	+	+	+
N's Payoff	+	+	+

Note: + indicates increase, − indicates decrease, ≈0 indicates no change.

period, so that the incremental increase of capital needed in the bad state is reduced (relative to the case when capital requirements in the first period are not altered). This endogenous response weakens the adverse effects of ex post capital requirements on financial institutions' payoffs. Therefore, putting these two requirements together with a small margin requirement makes everyone at least as well off as in the baseline case.

We also considered a combination that involves margins, along with period 1 liquidity requirements and capital requirements in the bad state. Any time a liquidity requirement is imposed, it triggers the same portfolio adjustments by the bank in period 1 as if the bank had its capital requirement in the bad state increased. This effect proves so powerful that the capital ratio in the bad state becomes so much higher that the regulation is not binding. Hence, these bundles amount to studying liquidity requirements, with margin requirements, and *a less countercyclical set of capital standards*; the capital ratio in period 1 is little affected but remains above the capital ratio in period 2. So it is not really possible to do an isolated experiment that moves only margins, ex ante liquidity, and ex post capital regulations.

The second column of table 3 shows a regulatory bundle featuring higher margins, along with increased ex ante capital and liquidity regulations. This combination leaves F worse off. Based purely on the individual effects from table 2, this might at first seem surprising. The reason why this combination delivers a strange interaction is because it stifles the bank's ability to expand credit. On the one hand, the liquidity requirements force it to expand short-term lending (which is naturally limited by the first-period wealth of R and P), while on the other, the margin requirements limit the shadow bank's ability to absorb securitization. Faced with these roadblocks, the bank cuts total credit and, because of its preference for smooth profits, it spreads the credit reduction over both period 1 and period 2. P benefits partly because the lower loan limits reduce the size of this default in the bad state, but F only sees the reduction in credit and winds up worse off.

The last combination considered in table 3 shows the effects of packaging capital requirements in both periods with tighter loan-to-value regulation. This amounts to substituting a loan-to-value restriction for a margin requirement. From our analysis of the one-at-a-time regulatory interventions, we would expect this to be a less good permutation. This intuition is confirmed, as the welfare of both P and F drop when the LTV rules are imposed.[7] The losses are attributable to the reduction in total credit that is induced by the increased downpayment requirements—just as when it was imposed as a single regulation. Credit availability falls in both periods, so P sees a sharp drop in mortgage credit and F is able to borrow less in the boom state. Thus, both borrowers are made worse off by raising downpayment requirements instead of margin requirements.

We draw three conclusions from the results from analyzing the results in table 3. First, while this model has multiple ways in which the financial system can amplify shocks, it is not the case that regulatory interventions with multiple tools are necessarily welfare enhancing. One of the more obvious policy packaging that at first glance might be appealing actually is welfare reducing. Indeed, it is easy to put together many other combinations of policies that have unintended effects.

Second, the reason why some of the policy bundles in table 3 did not work accords with the intuition we have emphasized about paying attention to the channels through which regulations operate.

[7] To make sure the comparison between columns 1 and 3 is reasonable, we calibrate the increase in LTV in column 3 to match the endogenous change in the LTV that occurs naturally in column 1. If the LTV and margins were identical tools, then the equilibrium should not change, but as seen in the table, things change considerably.

For example, combining two ex ante regulations that control bank risk taking is unnatural when considering their expected economic effects, even though blindly using the results in table 2 might suggest trying this combination. The more successful package combines regulations that operate via fairly different channels.

Finally, and most importantly, the only way to conduct this type of exercise is to use a full general equilibrium model. There would simply be no way to guess confidently, based on partial equilibrium hunches, which policies would be complements and substitutes and which ones would have unfortunate interactions when they are implemented simultaneously.

6. Conclusions

Our approach to studying financial regulation highlights the substantial payoff to having a formal general equilibrium model that takes a clear stand on the purpose and highlights risks associated with having a financial system that includes both banks and shadow banks that deliver funding to the economy. Given many complex interactions between the various agents in the model, no single regulatory tool is going to be sufficient to offset the many distortions arising from a default. But it does appear that a bundle of tools can improve outcomes relative to the unregulated equilibrium that the economy would reach.

The optimal regulatory mix in any particular calibration is sensitive to the starting parameterization and the associated initial equilibrium. Nevertheless, given all the frictions in the model, this initial equilibrium will typically be third best—i.e., constrained Pareto inefficient—so that there is, in principle, scope for moving to a better equilibrium.

We highlight groups of regulations that work in harmony towards alleviating the secondary effects from asset fire sales. Margin requirements are a valuable complement to other regulations because they contribute to the stability of the shadow banking system. Similarly, capital requirements that force banks to be better capitalized after an asset-price collapse also work well with other regulatory tools. The ex post requirement on bank health reduces bank risk taking and thereby contributes to the stability of the banking system. It also creates incentives for savers to diversify their portfolio choices, which bring other benefits.

In our framework the tools we describe are perhaps deceptively effective. For example, in the real world one big benefit of loan-to-value ratios is that they attach some loss-absorbing capital to housing purchases regardless of who winds up owning the securities that are issued against the houses. In our model this advantage is absent because a combination of a capital rule and a margin requirement forces all the financial institutions to have some skin in the game. So the static structure of the model means it is not well suited to handle the kind of innovation that takes place to avoid regulation. We recognize this consideration but still find the model to be a helpful first step for thinking about the interaction of different policies—which the model shows can be quite complicated.

The best regulatory combination that we identify also includes raising capital requirements ahead of an asset-price boom or bust. This restriction reduces bank risk taking without too severely limiting overall credit supply and also lowers the burden of requiring higher capital during bad times.

Importantly, we find that indiscriminate combinations of regulations can easily be welfare reducing. Simply piling on multiple regulations because there are multiple channels of financial contagion is not necessarily good. Instead, wise regulation requires that considerable care is taken to anticipate the ways in which policies will interact and to guard against creating perverse incentives and reactions.

As Kohn (2010, 2011) emphasized, we are in the early days of macroprudential analysis. There are still many unanswered questions. But the prospects of addressing these questions using this style of general equilibrium model are bright.

Appendix 1. Notation and Parameterization

The labeling convention indentifies agents with superscripts (P, F, R, B, N), and goods (p and h) and periods/states $(1, 2g, 2b)$ with subscripts. The following table presents the notation used for the exogenous and endogenous variables in the model. Superscripts and subscripts are not shown to save space.

Table 4. List of Variables

$\boldsymbol{e}$	Endowments of potatoes or houses	$\boldsymbol{c}$	Consumption of potatoes or housing
$\boldsymbol{Money}$	Monetary endowments of households	$\boldsymbol{q}$	Quantity of potatoes or housing sold
$\boldsymbol{E}$	Capital of financial institutions	$\boldsymbol{LST}$	Quantity of short-term loans
$\boldsymbol{P}$	Prices of potatoes, housing, or MBS	$\boldsymbol{MORT}$	Quantity of mortgages
$\boldsymbol{r}$	Interest rates on short-term loans, on discount window borrowing, on deposits, on mortgages, or on repo loans	$\boldsymbol{REPO}$	Quantity of repo loans
$\boldsymbol{\tau}$	Marginal non-pecuniary penalty for default on mortgages, deposits, or repo loans	$\boldsymbol{D}$	Quantity of deposits
γ	Risk-aversion coefficients	$\boldsymbol{DISC}$	Quantity of discount window loans made by the central bank to the commercial bank
$\boldsymbol{\omega}$	Probability of good or bad state	$\boldsymbol{MBS}$	Quantity of mortgage-backed securities sold
$\boldsymbol{\xi}$	Time discount factor	$\boldsymbol{\sigma}$	Percentage of retained mortgages sold
$\boldsymbol{\delta}$	Depreciation rate	$\boldsymbol{v}$	Percentage of returned MBS that are resold (rate of fire sales)
$\boldsymbol{U}$	Utility of households	$\boldsymbol{V}$	Repayment rate on mortgages or deposits
$\boldsymbol{Prof}$	Profit function	$\boldsymbol{CC}$	Cash committed for mortgage extension by the commercial bank
$\boldsymbol{\pi}$	Profits of financial institutions	$\boldsymbol{cash}$	Cash assets held by the commercial bank

Table 5. Exogenous Variables

Endowments of Goods	Households' Wealth	F.I. Capital	CB Rates	Default Penalties	Risk Aversion	Other Parameters
$e^P_{1,p} = 10$	$Money^P_1 = 4.1$	$E^B_1 = 0.5$	$r^{CB}_1 = 0.12$	$\tau^P_{2b} = 4$	$\gamma^P = 2.1$	$\omega_{2b} = 0.1$
$e^P_{2g,p} = 32$	$Money^P_{2g} = 4.1$	$E^B_{2g} = 0.5$	$r^{CB}_{2g} = 0.12$	$\tau^B_{2g} = 1.2$	$\gamma^F = 2.1$	$\xi = 0.85$
$e^P_{2b,p} = 5.8$	$Money^P_{2b} = 0.1$	$E^B_{2b} = 0$	$r^{CB}_{2b} = 0.20$	$\tau^\beta_{2b} = 1.2$	$\gamma^R = 2.4$	$\delta = 0.15$
$e^F_{2g,p} = 11$	$Money^F_{2g} = 4.1$	$E^N_1 = 1$		$\tau^N_{2b} = 0.2$	$\gamma^B = 1.4$	
$e^F_{2b,p} = 11$	$Money^F_{2b} = 2.1$	$E^N_{2g} = 2$			$\gamma^N = 0.7$	
$e^R_{1,h} = 1$	$Money^R_1 = 6.5$	$E^N_{2b} = 1$				
$e^R_{2g,h} = 0$	$Money^R_{2g} = 0$					
$e^R_{2b,h} = 0$	$Money^R_{2b} = 0$					

Table 6. Initial Equilibrium Variables

Prices	Interest Rates	Aggregate Consumption		Loans		Securitization	Delivery Rates	F.I. Profits
$P_{1,p} = 1.48$	$r_1^{ST} = 0.12$	$c_{1,p}^P = 0.827$	$c_{1,p}^R = 9.173$	$LST_1^P = 12.10$	$LST_1^B = 50.70$	$MBS_1^B = 21.95$	$V_{2g}^{MORT} = 1$	$\pi_1^B = 0.68$
$P_{2g,p} = 1.33$	$r_{2g}^{ST} = 0.12$	$c_{2g,p}^P = 1.289$	$c_{2g,p}^R = 41.320$	$LST_{2g}^P = 38.48$	$LST_{2g}^B = 64.11$	$\sigma_{2g}^B = 0.281$	$V_{2b}^{MORT} = 0.55$	$\pi_{2g}^B = 1.01$
$P_{2b,p} = 1.60$	$r_{2b}^{ST} = 0.20$	$c_{2b,p}^P = 0.295$	$c_{2b,p}^R = 15.874$	$LST_{2b}^P = 7.33$	$LST_{2b}^B = 21.13$	$\sigma_{2b}^B = 0$	$V_{2g}^D = 1$	$\pi_{2b}^B = 1.00$
$P_{1,h} = 676.02$	$r^D = 0.34$	$c_{1,h}^P = 0.064$	$c_{1,h}^R = 0.936$	$MORT^P = 27.02$	$DISC_1^B = 44.68$	$\vartheta_{2b}^B = 0.063$	$V_{2b}^D = 0.60$	$CC^B = 5.60$
$P_{2g,h} = 1{,}111.18$	$r^{MORT} = 0.58$	$c_{2g,h}^P = 0.052$	$c_{2g,h}^R = 0.783$	$LST_{2g}^F = 12.63$	$DISC_{2g}^B = 96.94$	$MBS_{2g}^N = 1.42$		$cash_1^B = 6.74$
$P_{2b,h} = 362.83$	$r^{REPO} = 0.57$	$c_{2b,h}^P = 0.020$	$c_{2b,h}^R = 0.796$	$LST_{2b}^F = 13.80$	$DISC_{2b}^B = 38.74$	$MBS_{2b}^N = 1.39$		$\pi_{2g}^N = 4.82$
$P_{1,MBS} = 0.98$	$M_1^{CB} = 44.68$	$c_{2g,p}^F = 0.391$		$LST_1^R = 38.59$	$REPO^B = 20.41$			$\pi_{2b}^N = 1.20$
$P_{2g,MBS} = 1.41$	$M_{2g}^{CB} = 96.94$	$c_{2b,p}^F = 0.631$		$LST_{2g}^R = 13.00$				
$P_{2b,MBS} = 0.72$	$M_{2b}^{CB} = 38.74$	$c_{2g,h}^F = 0.015$		$LST_{2b}^R = 0.005$				
		$c_{2b,h}^F = 0.044$		$D^R = 31.53$				

Appendix 2. Optimization and Equilibrium

This section presents the objective functions and budget constraints for the main actors in the model. For full details, see GKTV (2012).

Household P's Optimization Problem

Household P maximizes its intertemporal expected utility from the consumption of potatoes and housing. The last term in the utility function represents the reputational penalty from default, which is proportional to the loss given default on mortgages.

$$\begin{aligned}\max \overline{U}^P &= U^P(c^P_{1,p}, c^P_{1,h}) + \xi \cdot \omega_{2g}[U^P(c^P_{2g,p}, (1-\delta)c^P_{1,h} + c^P_{2g,h})] \\ &\quad + \xi \cdot \omega_{2b}[U^P(c^P_{2b,p}, c^P_{2b,h}) \\ &\quad - \tau^P_{2b}[MORT^P(1+r^{MORT}) - P_{2b,h}c^P_{1,h}]],\end{aligned}$$

where $U^P(c^P_{ts,p}, c^P_{ts,h}) = \frac{1}{1-\gamma^P}(c^P_{ts,p})^{1-\gamma^P} + \frac{1}{1-\gamma^P}(c^P_{ts,h})^{1-\gamma^P}$ subject to the following budget constraints:

$$P_{1,h}c^P_{1,g} \leq Money^P_1 + MORT^P + LST^P_1,$$

i.e., the purchase of housing in the initial period is funded by own monetary endowments, a mortgage, and short-term borrowing;

$$LST^P_1(1 + r^{ST}_1) \leq P_{1,p}q^P_{1,p},$$

i.e., the revenues from potatoes sales are used to repay the short-term loans at the end of the initial period;

$$MORT^P(1 + r^{MORT}) + P_{2g,h}c^P_{2g,h} \leq Money^P_{2g} + LST^P_{2g},$$

i.e., the repayment of the mortgage in the good state and the new housing purchases are funded by own monetary endowments and short-term borrowing;

$$LST^P_{2g}(1 + r^{ST}_{2g}) \leq P_{2g,p}, q^P_{2g,p},$$

i.e., the revenues from potatoes sales in the good state are used to repay the short-term loans at the end of the second period;

$$P_{2b,h}, c^P_{2b,h} \leq Money^P_{2b} + LST^P_{2b},$$

i.e., own monetary endowments and short-term borrowing are the only funds used for the new housing purchases in the bad state, since households default on their mortgages; and

$$LST_{2b}^{P}(1 + r_{2b}^{ST}) \leq P_{2b,p}, q_{2b,p}^{P},$$

i.e., the revenues from potatoes sales in the bad state are used to repay the short-term loans at the end of the second period.

Household F's Optimization Problem

Household F enters the economy only in the second period. Thus, it lives in either the good or the bad state and it aims at maximizing utility in either state from the consumption of potatoes and housing.

$$\max U^F(c_{2s,p}^F, c_{2s,h}^F),$$

where $U^F(c_{2p}^F, c_{2h}^F) = \frac{1}{1-\gamma^F}(c_{2p}^F)^{1-\gamma^F} + \frac{1}{1-\gamma^F}(c_{2h}^F)^{1-\gamma^F}$ subject to the following budget constraints:

$$P_{2s,h}c_{2s,h}^F \leq Money_{2s}^F + LST_{2s}^F,$$

i.e., housing purchases are funded by own monetary endowments and short-term borrowing, and

$$LST_{2s}^F(1 + r_{2s}^{ST}) \leq P_{2s,p}, q_{2s,p}^F,$$

i.e., the revenues from potatoes sales are used to repay the short-term loans.

Household R's Optimization Problem

Household R maximizes its intertemporal expected utility from the consumption of potatoes and houses.

$$\max \overline{U}^R = U^R(c_{1,p}^R, c_{1,h}^R) + \xi \cdot \omega_{2g}[U^R(c_{2g,p}^R, (1-\delta)c_{1,h}^R + c_{2g,h}^R)] \\ + \xi \cdot \omega_{2b}[U^R(c_{2b,p}^R, (1-\delta)c_{1,h}^R + c_{2b,h}^R)]$$

where $U^R(c_{s,p}^R, c_{s,h}^R) = \frac{1}{1-\gamma^R}(c_{s,p}^R)^{1-\gamma^R} + \frac{1}{1-\gamma^R}(c_{s,h}^R)^{1-\gamma^R}$ subject to the following budget constraints:

$$P_{1,p}c_{1,p}^R + D^R \leq Money_1^R + LST_1^R,$$

i.e., potatoes purchases and deposits at the commercial bank are funded by own monetary endowments and short-term borrowing;

$$LST_1^R(1 + r_1^{ST}) \leq P_{1,h}q_{1,h}^R,$$

i.e., the revenues from housing sales are used to repay the short-term loans at the end of the initial period;

$$P_{2s,p}c_{2s,p}^R \leq Money_{2s}^R + LST_{2s}^R + V_{2s}^D D^R(1 + r^D),$$

i.e., potatoes purchases in state s in the second period are funded by own monetary endowments, short-term borrowing, and the received repayment on deposits; and

$$LST_{2s}^R(1 + r_{2s}^{ST}) \leq P_{2s,h}q_{2s,h}^R,$$

i.e., the revenues from housing sales in state s are used to repay the short-term loans at the end of the second period.

Commercial Bank B's Optimization Problem

The commercial bank aims at maximizing a concave function of profits made in both periods. The last term in the payoff function represents the reputational loss from default, which is proportional to the loss given default on deposits.

$$\begin{aligned} \max \overline{Prof}^B &= Prof^B(\pi_1^B) \\ &\quad + \xi\Sigma_s\omega_{2s}[Prof^B(\pi_{2s}^B) - \tau_{2s}^B[1 - v_{2s}^B]D^B(1 + r^D)], \end{aligned}$$

where $Prof(\pi_{ts}^B) = \frac{1}{1-\gamma^B}(\pi_{ts}^B)^{1-\gamma^B}$ subject to the following budget constraints:

$$LST_1^B + REPO^B + CC^B \leq E_1^B + DISC_1^B + D^B,$$

i.e., the commercial bank uses its own capital together with funds borrowed from the discount window and deposits to supply short-term and repo loans and to hold a cash amount committed to the extension of mortgages;

$$MORT^B \leq CC^B + P_{1,MBS}MBS_1^B,$$

i.e., the commercial bank funds the extension of mortgages with its own committed cash and with the proceeds from the securitization of mortgages;

$$DISC_1^B(1 + r_1^{CB}) + cash_1^B \leq LST_1^B(1 + r_1^{ST}),$$

i.e., a part of the proceeds from the repayment of short-term loans is used to repay the loans from the discount window and the rest is held as cash reserves;

$$LST_{2g}^B + v_{2g}^B D^B(1 + r^D) \leq cash_1^B + E_{2g}^B + DISC_{2g}^B + P_{2g,MBS}\sigma_{2g}^B(MORT^B - MBS_1^B),$$

i.e., the commercial bank uses its cash reserves and new capital together with borrowed funds from the discount window and revenues from further securitization of retained mortgages to repay depositors and extend new short-term lending in the good state in the second period;

$$\pi_{2g}^B \leq LST_{2g}^B(1 + r_{2g}^{ST}) + REPO^B(1 + r^{REPO}) + (1 - \sigma_{2g}^B)(MORT^B - MBS_1^B)(1 + r^{MORT}) - DISC_{2g}^B(1 + r_{2g}^{CB}),$$

i.e., the profits in the good state are equal to the profit on short-term lending plus the repayment on repo loans and the mortgages remaining in the balance sheet less the loans that must be repaid to the central bank;

$$LST_{2b}^B + v_{2b}^B D^B(1 + r^D) \leq cash_1^B + E_{2b}^B + DISC_{2b}^B + P_{2b,MBS}[\vartheta_{2b}^B MBS_1^B + \sigma_{2b}^B(MORT^B - MBS_1^B)],$$

i.e., the commercial bank uses its cash reserves and new capital together with borrowed funds from the discount window and revenues from further securitization of retained mortgages and from returned MBS that are resold to repay depositors and extend new short-term lending in the bad state in the second period; and

$$\pi_{2b}^B \leq LST_{2b}^B(1 + r_{2b}^{ST}) + V_{2b}^{MORT}(MORT^B - \vartheta_{2b}^B MBS_1^B - \sigma_{2b}^B(MORT^B - MBS_1^B))(1 + r^{MORT}) - DISC_{2b}^B(1 + r_{2b}^{CB}),$$

i.e., the profits in the bad state are equal to the profits on short-term lending plus the repayment on the mortgages remaing in the balance sheet less loans that must be repaid to the central bank.

Shadow Bank N's Optimization Problem

The non-bank aims at maximizing a concave function of profits made in the second period, since it does not make any profits in the initial one. The last term in the payoff function represents the reputational loss from default, which is proportional to the loss given default on repo loans.

$$\begin{aligned}\max \overline{Prof}^N = \xi \cdot \omega_{2g} Prof^N(\pi_{2g}^N) + \xi \cdot \omega_{2b}[Prof^N(\pi_{2b}^N) \\ - \tau_{2b}^N[REPO^N(1 + r^{REPO}) \\ - V_{2b}^{MORT} MBS_1^N(1 + r^{MORT})]],\end{aligned}$$

where $Prof(\pi_{2s}^N) = \frac{1}{1-\gamma^N}(\pi_{2s}^N)^{1-\gamma^N}$ subject to the following budget constraints:

$$P_{1,MBS} MBS_1^N \leq E_1^N + REPO^N,$$

i.e., the initial purchase of mortgage-backed securities is funded by own capital and a repo loan;

$$P_{2s,MBS} MBS_{2s}^N \leq E_{2s}^N,$$

i.e., the purchase of mortgage-backed securities in the second period is funded out of new capital, which implies cash-in-market pricing;

$$\pi_{2g}^N \leq (MBS_1^N + MBS_{2g}^N)(1 + r^{MORT}) - REPO^N(1 + r^{REPO}),$$

i.e., the profits in the good state are equal to the repayment on the mortgage-backed securities purchased in both the initial period and the good state minus the repayment of the repo loan; and

$$\pi_{2b}^N \leq V_{2b}^{MORT} MBS_{2b}^N)(1 + r^{MORT}),$$

i.e., the profits in the bad state are equal to the repayment of returned mortgage-backed securities repurchased.

Markets and Equilibrium

Equilibrium is reached when all agents maximize their payoff functions subject to their budget constraints, all markets clear, and their expectations are rational. Potato prices in equilibrium are determined by the clearing of the potato market. Supply equals demand in every period and state in equilibrium, i.e., $q^P_{1,p} = c^R_{1,p}$ and $q^P_{2s,p} + q^F_{2s,p} = c^R_{2s,p}$. Similarly, $q^R_{1,h} = c^P_{1,h}, q^R_{2g,h} = c^P_{2g,h} + c^F_{2g,h}$ and $q^R_{2b,h} + c^P_{1,h} = c^P_{2b,h} + c^F_{2b,h}$ for the housing market in equilibrium. Moreover, the loan/deposit markets clear when $MORT^P = MORT^B, REPO^B = REPO^N, D^R = D^E, LST^B_1 = LST^P_1 + LST^R_1$, and $LST^B_{2s} = LST^P_{2s} + LST^R_{2s} + LST^F_{2s}$. The market clearing for mortgage-backed securities requires $MBS^B_1 = MBS^N_1, \sigma^B_{2g}(MORT^B - MBS^B_1) = MBS^N_{2g}$, and $\vartheta^B_{2b} MBS^B_1 + \sigma^B_{2b}(MORT^B - MBS^B_1) = MBS^N_{2b}$. Finally, the demand from the commercial bank determines the equilibrium level of borrowing from the discount window, since there is a perfectly elastic supply from the central bank at predetermined interest rates.

Appendix 3. Definition of Regulatory Ratios

Loan-to-Value Regulation on Mortgages

Loan-to-value regulation sets the maximum level of mortgage borrowing for a given value of collateral pledged. Given that mortgage extension takes place only in the initial period, this is an ex ante tool.

$$\frac{MORT^P}{P_{1,h} c^P_{1,h}} \leq \text{ Maximum permissible } \textit{loan to value ratio}$$

Haircut Regulation on Repo Loans

Haircut regulation sets the minimum downpayment for a repo loan used to purchase mortgage-backed securities. As such, it can be implemented before the resolution of uncertainty, and it is an ex ante tool as well.

$$\frac{E^N_1}{P_{1,MBS} MBS^N_1} \geq \textit{ Margin requirement}$$

Bank Capital Regulation

Contrary to the aforementioned regulatory interventions, capital regulation does not attempt to regulate specific markets (mortgage or repo loan markets), but rather attempts to affect the incentives of the commercial bank to extend credit. Capital requirements are risk weighted in the spirit of the Basel Accord. Short-term loans are safe and thus should have a zero risk weight; i.e., they are not included in the calculation of risk-weighted assets. Capital regulation will differ depending on the point in time that it is implemented. For example, regulating capital requirements in the initial period affects the extension of repo loans differently than imposing them once the default state has realized. In the former case, repo loans multiplied by their ex ante risk weight count as part of risk-weighted assets. In the latter case, after default they are written off and thus generate losses that reduce equity that is in the numerator of the ratio. Thus, capital requirements can be both an ex ante and an ex post regulatory tool.

$$\frac{E_1^B + \pi_1^B}{rw_1^{MORT} \cdot (MORT^B - MBS_1^B) + rw_1^{REPO} \cdot REPO^B} \geq \text{Capital Requirement in initial period}$$

$$\frac{E_1^B + E_{2b}^B + \pi_1^B + P\_L_{mid2b}^B}{rw_{2b}^{MORT} \cdot (MORT^B - \vartheta_{2b}^B MBS_1^B)} \geq \text{Capital requirement in the bad state}$$

Bank Liquidity Regulation

Like capital regulation, liquidity requirements alter the commercial bank's incentives to offer different types of credit. But these regulations skew choices based on an asset's liquidity rather than the asset's credit risk. Short-term loans are considered liquid, while mortgages and repo loans, being long term and partially collateralized, are illiquid. As explained in the text, if liquidity requirements are imposed in the bad state, they exacerbate fire sales. So we consider liquidity regulation only in the initial period.

$$\frac{LST_1^B}{LST_1^B + REPO^B + MORT^B - MBS_1^B}$$
$$\geq \textit{ Liquidity requirement in initial period}$$

Dynamic Provisioning

Dynamic provisioning is formalized as a requirement for the bank to keep cash on its balance sheet throughout the good state of the world when the growth of real-estate-related credit, $g\%$, exceeds a certain threshold $x\%$. Letting the per-unit requirement be denoted by κ, such regulation would imply that the gross dynamic provisioning is $(g\% - x\%)\kappa$.

The budget constraints of the bank in the good state would then become

$$LST_{2g,p}^B + LST_{2g,h}^B + v_{2g}^B D^B(1 + r^D) + (g\% - x\%)\kappa$$
$$\leq cash_1^B + E_{2g}^B + DISC_{2g}^B + P_{2g,MBS}\sigma_{2g}^B(MORT^B - MBS_1^B)$$

and

$$\pi_{2g}^B \leq (g\% - x\%)\kappa + LST_{2g,p}^B(1 + r_{2g,p}^{ST}) + LST_{2g,h}^B(1 + r_{2g,h}^{ST})$$
$$+ REPO^B(1 + r^{REPO}) + (1 - \sigma_{2g}^B)(MORT^B - MBS_1^B)$$
$$\times (1 + r^{MORT}) - DISC_{2g}^B(1 + r_{2g}^{CB}),$$

where the growth rate in real-estate-related credit is

$$g\% = \frac{LST_{2g,h}^B}{MORT^B + LST_{2,h}^B} - 1)\%.$$

Note that the short-term real-estate-related credit in the first period, $LST_{1,h}^B$, is equal to the short-term loan demand of household P, LST_1^P, while in the good state it is equal to the loan demands of both P and F, i.e., $LST_{2g,h}^B = LST_{2g}^P + LST_{2g}^F$.

References

Adrian, T., and H. S. Shin. 2009. "The Shadow Banking System: Implications for Financial Regulation." Federal Reserve Bank of New York Staff Report No. 382.

Allen, F., and D. Gale. 1994. "Liquidity Market Participation and the Volatility of Asset Prices." *American Economic Review* 84 (4): 933–55.

Bernanke, B. S. 2007. "The Financial Accelerator and the Credit Channel." Speech at the Credit Channel of Monetary Policy in the Twenty-first Century Conference, Federal Reserve Bank of Atlanta, Atlanta, Georgia, June 15.

Bernanke, B. S., M. Gertler, and S. Gilchrist. 1999. "The Financial Accelerator in a Quantitative Business Cycle Framework." In *Handbook of Macroeconomics*, ed. J. B. Taylor and M. Woodford, Edition 1, Vol. 1, 1341–93 (chapter 21). Elsevier.

Brunnermeier, M., and L. H. Pedersen. 2009. "Market Liquidity and Funding Liquidity." *Review of Financial Studies* 22 (6): 2201–38.

Curdia, V., and M. Woodford. 2010. "Credit Spreads and Monetary Policy." *Journal of Money, Credit and Banking* 42 (1): 3–35.

Dubey, P., J. Geanakoplos, and M. Shubik. 2005. "Default and Punishment in General Equilibrium." *Econometrica* 73 (1): 1–37.

Goodhart, C. A. E., A. K. Kashyap, D. P. Tsomocos, and A. P. Vardoulakis. 2012. "Financial Regulation in General Equilibrium." NBER Working Paper No. 17909.

Kiyotaki, N., and J. Moore. 1997. "Credit Cycles." *Journal of Political Economy* 105 (2): 211–48.

Kohn, D. L. 2007. "Financial Stability and Policy Issues." Speech at the Federal Reserve Bank of Atlanta's 2007 Financial Markets Conference, Sea Island, Georgia, May 16.

———. 2010. "Monetary Policy in the Crisis: Past, Present, and Future." Speech at the Brimmer Policy Forum, American Economic Association Annual Meeting, Atlanta, Georgia, January 3. Available at http://www.federalreserve.gov/newsevents/speech/kohn20100103a.htm.

———. 2011. "The Financial Policy Committee at the Bank of England." Speech at the U.S. Department of the Treasury Conference, December 2. Available at http://www.bankofengland.co.uk/publications/Documents/speeches/2011/speech536.pdf.

Kroszner, R. S. 2007. "Analyzing and Assessing Banking Crises." Speech (via videoconference) at the Federal Reserve Bank of San Francisco, Conference on the Asian Financial Crisis Revisited, San Francisco, California, September 6.

Mishkin, F. S. 2007. "Will Monetary Policy Become More of a Science?" FEDS Paper No. 2007-44, Board of Governors of the Federal Reserve System.

Shleifer, A., and R. Vishny. 2011. "Fire Sales in Finance and Macroeconomics." *Journal of Economic Perspectives* 25 (1): 29–48.

Tucker, P. 2010. "Shadow Banking: Financing Markets and Financial Stability." Speech at the BCG Partners Seminar, London, January 21.

Woodford, M. 2003. *Interest and Prices: Foundations of a Theory of Monetary Policy*. Princeton, NJ: Princeton University Press.