A dynamic model of bank behaviour under multiple regulatory constraints

Markus Behn,* Claudio Daminato,† Carmelo Salleo,‡

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Abstract

We develop a structural model of bank behaviour that helps to understand how banks adjust their asset and liability structures in response to changes in regulatory capital and liquidity requirements or economic shocks. When adjusting their balance sheet structure bank managers need to consider various trade-offs simultaneously. Generally, taking more risk allows them to generate higher expected returns, while it increases the possibility of breaching regulatory requirements or having to raise fresh equity. As a result, banks hold precautionary buffers on top of capital and liquidity requirements. Reactions to regulatory changes or economic shocks are highly non-linear and depend on banks' initial asset and liability structure. More constrained banks generally react stronger and follow a different mode of adjustment, inter alia implying stronger reductions in loan supply. The model illustrates how capital and liquidity dimensions interact with each other and is useful for regulators and policy makers who are interested in the real effects of changes in capital and liquidity requirements.

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*European Central Bank, Frankfurt am Main, Germany, email to markus.behn@ecb.europa.eu
†ETH Zurich, Zurich, Switzerland, email to dclaudio@ethz.ch
‡European Central Bank, Frankfurt am Main, Germany, email to carmelo.salleo@ecb.europa.eu

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1 Introduction

Following the global financial crisis of 2007-08, policy makers around the world have launched a comprehensive reform programme aimed at increasing the banking sector's resilience against shocks. A key feature of this post-crisis regulatory framework is its multi-faceted nature, with banks being subjected to multiple regulatory constraints aimed at capturing the various risk dimensions on the solvency and liquidity side. Considering the variety of regulatory changes and the relative novelty of many reform elements, assessing the joint impact of the adapted framework on banks and the real economy is a challenging task for both regulators and academics (Financial Stability Board 2017). Existing models and empirical studies on regulatory impact assessment often focus on the effects of higher capital requirements on lending, while there is little evidence on the effects of liquidity regulation and the interaction of the various rules.[1] Moreover, the theoretical banking literature has mainly been interested in normative, general equilibrium considerations with respect to the optimal level of regulation (see, e.g., Diamond and Rajan 2000, 2001, Admati and Hellwig 2013, DeAngelo and Stulz (2015)), and empirical evidence on banks' reactions is often limited to reduced form estimates that make it difficult to foresee future adjustments (see, e.g., Aiyar et al. 2014, Behn et al. 2016b, Jiménez et al. 2017).

In this paper, we develop a dynamic partial equilibrium model of bank behavior that aims at addressing these challenges by providing a microeconomic foundation for banks' capital and liquidity structures as well as their adjustments in response to regulatory changes and economic shocks. The model takes a private perspective, which is justified by the observation that banks' private adjustment decisions often transmit to the real economy via their impact on aggregate loan supply. Moreover, the model features regulatory constraints on risk-weighted capital ratios and liquidity ratios and is well suited for studying the interaction between these different types of requirements.

The stylized bank balance sheet in the model comprises loans and liquid assets on the asset side, and deposits, long- and short-term debt and equity on the liability side. Banks face uncertainty with respect to assets returns, funding costs, and deposit volumes, and need to consider various trade-offs simultaneously when taking decisions on how to adjust their balance sheet structure. Generally, taking more risk allows them to generate higher expected returns, while at the same time increasing the risk of breaching regulatory capital and/or liquidity requirements or having to raise fresh equity in the market. To insure against profitability shocks on the asset and/or funding side that can push capital ratios down, banks may hold additional

[1]See, for instance, Berger et al. (2008), Flannery and Rangan (2008), Mehran and Thakor (2011), or Allen et al. (2015). An early survey on the effects of capital requirements is provided by Thakor (1996). More recently, some papers started to investigate how multiple constraints interact with each other (e.g., Cecchetti and Kashyap 2016, Chami et al. 2017, Goel et al. 2017, Mankart et al. 2018).

voluntary buffers on top of minimum capital requirements.[2] A similar precautionary motive for voluntary buffers arises on the liquidity side, where banks need to have a sufficient amount of liquid assets to insure against possible outflows of deposits or fluctuations in liquid asset prices or the cost of short-term debt. Our model provides an economic rationale for the magnitude of these voluntary capital and liquidity buffers and thus provides insights on the importance of precautionary motives in determining banks' actual capital and liquidity structures.[3] Moreover, the rich characterisation of economic uncertainty, banks' balance sheet structure and choices embedded in the model allows analysing how capital and liquidity structures evolve over time, how regulatory requirements interact with each other in shaping these dimensions, and how banks adapt them in response to changes in capital or liquidity requirements. With respect to the latter, the model accommodates potential heterogeneity in banks' response functions, reflecting the possibility that reactions may depend on initial balance sheet conditions. This is important since different modes of adjustment may have different social implications, for example with respect to the evolution of aggregate loan supply and overall economic outcomes.

We estimate the model on data for 116 institutions supervised by the European Single Supervisory Mechanism (SSM), covering the quarters from 2014-Q1 to 2016-Q3 and containing very granular balance sheet and income statement information. Using a Simulated Method of Moments approach, the model's structural parameters are obtained by matching key balance sheet characteristics and dynamics observed in the actual supervisory data. The estimated structural parameters provide an explanation for voluntary capital and liquidity buffers based on precautionary motives (see, e.g., Brunnermeier and Sannikov 2014 and Valencia 2014) and confirm that regulatory requirements are important determinants of actual capital and liquidity structures. Moreover, the estimates are consistent with frictions that prevent banks from freely adjusting the amount of equity raised from external stakeholders. In line with the data, the model suggests that asset expansion is mainly financed by debt issuance, while equity tends to be relatively sticky, so that leverage is a major determinant of overall balance sheet size (see, e.g., Adrian and Shin 2011). More specifically, increases in liquid assets tend to be financed with short-term debt, while long-term debt and equity are more attractive when it comes to financing loans. Moreover, asset expansions are associated with a decrease in average asset risk,

[2]This precautionary motive for voluntary capital buffers is reminiscent of the models by Brunnermeier and Sannikov (2014) and Valencia (2014). Valencia (2016) provides empirical evidence supporting such a motive.

[3]A common view in the literature on bank capital structure is that holding capital imposes some kind of cost on banks who consequently operate with capital ratios close to the regulatory minimum (e.g., Mishkin 2004, Van den Heuvel 2008, Mehran and Thakor 2011, Allen et al. 2015, DeAngelo and Stulz 2015). In such a situation, even small changes in requirements can have large implications for the structure of banks' balance sheets and hence the real economy. Contrasting with this view, recent empirical evidence shows that there is vast heterogeneity in capital ratios, with many banks operating well-above the regulatory minimum (e.g., Flannery and Rangan 2008, Gropp and Heider 2010, Sorokina et al. 2017). This observation is consistent with papers arguing that the Modigliani and Miller (1958) capital structure irrelevance theorem can be extended to banks (e.g., Miller 1995, Admati et al. 2010, Kashyap et al. 2010, Admati and Hellwig 2013, Miles et al. 2013).

which is consistent with banks targeting a risk-weighted capital ratio (see, e.g., Berger et al. 2008, Flannery and Rangan 2008) and the Value-at-Risk rule of equity management sketched out in Adrian and Shin (2014). Finally, we observe a positive relation between changes in capital and liquidity ratios, illustrating that specific adjustment actions such as reshuffling from loans to liquid assets help to improve both ratios simultaneously.

Using the estimated model, we simulate banks' decisions under the actual economic and institutional conditions during our sample period and then conduct a number of counterfactual simulations to investigate how banks adjust asset and liability structures in response to policy and economic shocks. The counterfactual simulations illustrate that changes in capital and liquidity requirements can have a material impact on banks' asset and liability structures and, consequently, aggregate lending in the economy.

The estimated model suggests that banks fully replenish their voluntary capital buffer in response to changes in the minimum capital requirements (but go no further), in line with recent empirical evidence provided by Bahaj and Malherbe (2017). At first glance, this seems to justify the assumption of constant voluntary buffers that is often taken in models studying the relation between bank capital and lending. However, our model illustrates that there is considerable heterogeneity in the way in which banks move to higher capital ratios, with important implications for the supply of loans. Adjustments are achieved by a combination of accumulating additional capital, reducing assets, and shifting from loans to liquid assets, where the overall magnitude and the relative strength of these effects strongly depends on initial balance sheet conditions of the bank as well as the time elapsed since the policy change. Generally, banks that are initially more constrained (i.e., closer to the minimum capital requirement) choose socially less desirable adjustment strategies, reducing loans considerably more than banks that are initially less constrained. These results suggest that policy makers should account for initial balance sheet conditions in the banking sector when implementing policy changes, instead of assuming mechanical relations between capital levels and lending. Moreover, our model suggests considerable differences between transitory and medium- to long-term effects of higher capital requirements. While banks tend to reduce loans in the short run, they also accumulate additional capital by retaining earnings, which allows them to support lending at higher levels than before in the medium to long-run. Thus, our paper dispels claims that higher capital requirements will lead to *permanent* reductions in lending and reconciles empirical evidence on a negative short-run impact of higher capital requirements and positive long-run effects of higher capital ratios (e.g., Fraisse et al. 2015, Behn et al. 2016b, Jiménez et al. 2017 on the former, and Gambacorta and Shin 2016 on the latter).

We further show that also changes in liquidity requirements can have sizable real effects, depending in particular on their interaction with capital requirements. Following an increase in liquidity requirements banks react by holding a larger amount of liquid assets. Ceteris paribus, increasing the amount of assets decreases capital ratios, so that further adjustments are necessary if banks wish to maintain constant voluntary capital buffers.[4] Our results show that these adjustments can involve a reduction in loans, in particular for banks that are initially more constrained by the liquidity requirement. Moreover, capital and liquidity ratios correlate positively in general terms, and both capital and liquidity structures tend to become more stable following changes in either requirement. However, banks generally compensate lower risk taking on the asset side by taking more risk on the liability side, e.g. reducing the average maturity of debt contracts. Consequently, under certain circumstances the decrease in solvency risk that is usually associated with an increase in capital requirements may be accompanied by an increase in liquidity risk, so that the aggregate impact on the riskiness of banks' balance sheets depends on the relative importance of solvency and liquidity risk. Overall, our results illustrate that there are complex interactions between capital and liquidity regulations, and that a comprehensive view on all dimensions is necessary in order to avoid potential unintended consequences of regulatory policies.

Our paper connects to the literature on bank capital and liquidity structure. In contrast to our model, theoretical papers on bank capital structure often focus on the socially optimal level of bank capital, i.e. the capital structure of the bank that maximizes its value for all stakeholders. Usually, the bank's optimal capital structure trades off some kind of bankruptcy cost against advantages of high leverage, due to agency problems (e.g., Diamond and Rajan 2000, Acharya et al. 2016), compensation for liquidity production (e.g., DeAngelo and Stulz 2015), tax benefits (e.g., Gornall and Strebulaev 2015, Sundaresan and Wang 2016), the existence of deposit insurance (Allen et al. 2015), or simply the notion that equity is costly for banks for various reasons (e.g., Mehran and Thakor 2011). A number of papers also consider the interaction between capital structure and asset risk (Shleifer and Vishny 1992, DeYoung and Roland 2001, Greenlaw et al. 2008, Adrian and Shin 2010, 2014). Previous papers studying the dynamic adjustment of capital ratios have often used partial adjustment models, assuming the existence of target capital structures towards which banks adjust in case of deviations (see, e.g., Berger et al. 2008, Flannery and Rangan 2008, Gropp and Heider 2010, Memmel and Raupach 2010, De Jonghe and Öztekin 2015). While the concept is theoretically appealing, partial adjustment models are unable to distinguish between actual targeting behaviour and mean reversion due to purely mechanical reasons (see Shyam-Sunder and Myers 1999, Chen and Zhao 2007, Chang and Dasgupta 2009). Our model does not impose ex ante targeting behaviour, instead proposing a novel methodology to study the dynamic adjustment of bank capital and liquidity structures.

[4] The result depends on the extent to which increasing the amount of liquid assets makes capital requirements more binding. In reality, this is more likely to be the case for banks that are relatively more constrained by the Leverage Ratio (i.e., an unweighted capital requirement). The reason for this is that liquid sovereign assets carry a risk weight of zero percent in many jurisdiction and hence do not require any equity financing under the risk-based framework, while they do enter the denominator and can thus increase the bindingness of the Leverage Ratio.

The paper also relates to studies on the relationship between bank capital or liquidity and aggregate lending or real economic activity. One approach in this field is to use micro-level data in order to identify how banks adjust lending behaviour in response to specific policy changes or economic shocks (e.g., Peek and Rosengren 1997, Aiyar et al. 2014, Fraisse et al. 2015, Behn et al. 2016b, Jiménez et al. 2017). Another approach is to investigate historical correlations between fluctuations in bank capital and other variables of interest (e.g., Bernanke et al. 1991, Hancock and Wilcox 1993, 1998, Berrospide and Edge 2010, Noss and Toffano 2016, Gross et al. 2016). Virtually all of these studies rely on reduced form estimates of past behaviour, which may compromise their suitability for analysing the possible effects of future policy changes (see Lucas 1976). The structural nature of our model seeks to overcome this challenge, as it establishes a microeconomic foundation for observed adjustments in capital and liquidity ratios and thus allows deriving economically founded behavioural responses to changes in capital or liquidity requirements.

Finally, our paper adds to a small but growing literature studying the interaction of multiple requirements in the post-crisis regulatory environment. Closely related is the paper by Mankart et al. (2018), who develop a dynamic structural banking model to examine the interaction between risk-weighted capital ratios and unweighted leverage requirements while abstracting from the liquidity dimension. The same applies to Goel et al. (2017), who take a capital allocation perspective and also study the interaction between risk-based capital requirements and a simple leverage ratio. The interaction between Basel III type capital and liquidity requirements is studied by Cecchetti and Kashyap (2016) and Chami et al. (2017). The former paper investigates potential redundancy of different types of requirements, while the latter develops a dynamic model for bank holding companies and studies how different types of investments on the asset side interact with each other. Finally, a number of papers seek to assess the macroeconomic effects of multiple constraints on bank capital and liquidity (e.g., Covas and Driscoll 2014, Boissay and Collard 2016, Fender and Lewrick 2016). Our paper contributes to this literature by illustrating the trade-offs that banks need to consider in an environment with both capital and liquidity requirements in a dynamic setting, and by offering insights on how capital and liquidity requirements may interact to determine the response of banks to changes in either capital or liquidity requirements.

The remainder of the paper is organized as follows: we develop our model in the next section and describe the data set and estimation strategy in Section 3. Results of the estimation are presented in Section 4, and results of the counterfactual simulation are shown in Section 5. Finally, Section 6 concludes.

2 Model

We develop a dynamic stochastic model of bank behavior in the presence of economic uncertainty and regulatory constraints on capital and liquidity ratios. The model allows to study how banks take joint decisions with respect to asset growth, debt issuance, risk taking and payout policy, this way providing a microeconomic foundation for the observed bank capital structures and liquidity profiles and their dynamic adjustments.

2.1 Outline of the model

The stylized bank balance sheet in our model is illustrated in Figure 1. It comprises two classes of assets, loans and liquid assets, and four classes of liabilities, deposits, long- and short-term debt, and equity. Decisions on how to adjust these asset and liability classes are taken by risk-neutral managers in a discrete time, infinite horizon setting. These managers maximize shareholder value in each period by jointly determining asset growth and structure, dividend payout and the financing mix between short-term and long-term debt. Similarly to Kashyap and Stein (1995), we do not allow for interbank competition for deposits from households and non-financial corporations, but assume that fluctuations in such deposits are entirely exogenous. The reason for taking this assumption is that price competition for deposits is a long-term process, so that it is not possible for banks to simply adjust the amount of deposits in the short- to medium-term. Hence, if banks want to leverage up or down by taking additional debt, they need to rely on short- or long-term wholesale funding, consistently with the results in Adrian and Shin (2010, 2014) and in line with the sticky nature of deposits. Finally, the motivation for distinguishing between deposits and short-term funding in the model also comes from their differential treatment under Basel III liquidity regulation (see Section 2.6).

The model takes a classical shareholder value perspective under which bank managers maximize the expected stream of future dividends, and incorporates two types frictions: First, breaching regulatory capital and liquidity requirements imposes a cost on shareholders, which is reminiscent of the bankruptcy cost in classical trade-off theory models (see, for instance, Kraus and Litzenberger 1973 or Buser et al. 1981). The cost can be motivated by the risk for shareholders to be bailed in, possible restrictions on dividend payments, or other supervisory measures that may be imposed in case of a breach of requirements.[5] Second, raising fresh equity in the market is costly, due to the existence of direct transactional costs and indirect costs of raising equity, e.g. related to debt overhang problems (Myers 1977, Admati et al. 2012) or signaling costs (Myers and Majluf 1984). The assumption that raising new external funds is costly is com-

[5] Our model abstracts from potential agency problems between bank managers and shareholders. However, breaching requirements may also have personal consequences for managers who could be removed in such case.

mon in the banking literature (e.g., Greenwald et al. 1993, Kashyap and Stein 1995, Froot and Stein 1998, Stein 1998, Valencia 2014) and consistent with the observation that banks are often reluctant to tap the market for fresh equity. In line with pecking order theory, the cost does not apply if banks decide to accumulate capital from retained earnings. Importantly, both the costs of breaching minimum capital and liquidity requirements and the cost of raising fresh equity are not imposed ex ante but estimated within our model structure. Hence, our model allows to test both trade-off and pecking order theories, since a zero value for either cost parameter would imply a rejection of the respective theory.

As the model embodies a balance sheet structure with several asset and liability classes, a rich characterization of uncertainty, and regulatory constraints on risk-weighted capital and liquidity ratios, bank managers need to take decisions while considering risk-return trade-offs on various dimensions simultaneously. First, expected returns on loans are generally higher than expected returns on liquid assets, but also more volatile. Similarly, relying on deposits or short-term debt is generally cheaper for banks than using long-term debt or equity financing, but comes with higher liquidity risk or rollover problems. Moreover, asset and liability structures interact with each other: the lower expected return on liquid assets is (partly) compensated by a funding advantage, since liquid assets require a lower amount of equity financing (as they are less risky) and can more easily be financed with cheaper short-term debt (since doing so does not decrease the liquidity ratio). Thus, while loans generate higher expected returns they are usually financed with lower (and more expensive) leverage, which ensures that both loans and liquid assets are attractive from an investment standpoint. In addition, liquid assets are needed as insurance against liquidity shocks, as a fraction of depositors may withdraw their money at the end of each period. Finally, the extent with which banks are willing to fund themselves with equity depends on the ability to generate earnings that could be retained and the impatience of shareholders captured by the discount factor (which can be seen as a proxy for the cost of equity). Banks will then tend to keep larger voluntary capital and liquidity buffers the higher the costs of breaching regulatory requirements or having to raise fresh equity. Considering all these trade-offs simultaneously, banks take decisions on how to adjust asset and liability structure in response to both regulatory and financial shocks.

To manage dimensionality and focus on the questions we are interested in we take a number of modelling assumptions that reflect a partial equilibrium perspective.[6] First, we assume that banks are price takers whose decisions do not have any impact on asset returns. That is, rates on loans and liquid assets are determined in competitive markets, and banks can (up to a certain limit) expand their lending at the prevailing market rates. This assumption is justified by the short- to medium perspective taken by our model: while one would expect some interaction between loan volumes and interest rates in a long-term general equilibrium framework, we think

[6]We discuss throughout the paper how relaxing some of these assumptions would affect our results.

that it is unlikely that banks account for such long-run effects in their short-term adjustment decisions. Second, while we allow for a possible relation between the bank's cost of funding and its capital structure, we do not find any evidence of such relation in the data (see Section 3.2). A possible explanation for this result is that our sample period coincides with extraordinary monetary policy measures in the euro area. The excess liquidity resulting from these measures could have compressed interest rate spreads for banks with more risky balance sheet structures, so that the relationship between a bank's riskiness and its cost of funding got blurred. Another possible reason is that a large portion of the lending between financial intermediaries takes the form of collateralized transactions (such as repos), and the riskiness of the counterparty may be less relevant for pricing in such transactions.[7] Finally, we explicitly take a private perspective and develop a positive model of bank adjustment behaviour, taking regulatory requirements and economic conditions as exogenously given. That is, we do not consider any social costs or benefits that may be associated with higher capital or liquidity requirements, and we do not try to derive optimal levels for the requirements. Instead, we simply study the privately optimal behaviour of a value-maximizing bank under regulatory constraints and economic uncertainty. We think that this is an interesting thing to do, since banks' private adjustment decisions are likely to have broader social implications, e.g. via their effects on the overall supply of loans.

The following subsections include a description of the timing of events and decisions, the exogenous processes of the model, the decision variables, the evolution of profits, the dynamics of capital and liquidity structures, and banks' dynamic optimization problem.

2.2 The timing of events and decisions

The timing of events is illustrated in Figure 2. In each period, banks start with loans $L_{j,t}$, liquid assets $F_{j,t}$, equity $E_{j,t}$, deposits $D_{j,t}$, long-term debt $LT_{j,t}$ and short-term debt $ST_{j,t}$. Thereafter, banks take decisions on the payout policy $div_{j,t}$, the issuance of new loans $g^L_{j,t}$ and new long-term debt $g^{LT}_{j,t}$, and the adjustment of liquid assets $g^F_{j,t}$ and short-term debt $g^{ST}_{j,t}$. They take these decisions to maximize:

$$\mathbb{E}_t\Bigg[\sum_{s=t}^{T}\beta^{s-t}\Bigg(\underbrace{div_{j,t+s}}_{\text{future dividends}} - \underbrace{\Omega \times \mathbb{1}(CR_{j,t+s} < \theta_{CR})}_{\text{cost of breaching capital requirements}} \tag{1}$$

$$- \underbrace{\Psi \times \mathbb{1}(LR_{j,t+s} < \theta_{LR})}_{\text{cost of breaching liquidity requirements}} - \underbrace{\Phi_1(-div_{j,t+s})^{\Phi_2} \times \mathbb{1}(div_{j,t+s} < 0)}_{\text{cost of raising fresh equity}}\Bigg)\Bigg]$$

with $\beta < 1$ being the discount factor and $\sum_{s=t}^{T}\beta^{s-t}div_{j,t+s}$ representing the stream of expected future dividends. The remaining terms of the expression reflect the frictions of our model. First,

[7] A negative relation between capital ratios and the cost of funding would facilitate adjustments and provide additional incentives to opt for higher capital ratios.

the variables Ω and Ψ represent the costs of falling below regulatory capital (θ_{CR}) and liquidity requirements (θ_{LR}), reflecting adverse consequences for shareholders that are likely to occur in such an event. Second, when raising fresh equity in the market ($div_{j,t} < 0$) banks pay a cost equal to $\phi_1(-div_{j,t+s})^{\phi_2}$, reflecting the existence of direct transactional costs and indirect costs related to external equity issuances.

The structural parameters β, Ω, Ψ, Φ_1 and Φ_2 are crucial elements in determining banks' adjustment functions and are estimated making use of the economic model (see Section 3.2). Given the structural parameters, the evolution of balance sheets depends on banks' decisions $\mathbf{\Gamma_{j,t}} = (div_{j,t}, g^L_{j,t}, g^F_{j,t}, g^{LT}_{j,t}, g^{ST}_{j,t})$ and realized profits. Profits, in turn, depend on banks' decisions and the realization of shocks on asset returns, cost of funding, and the volume of deposits (see next subsection).

2.3 Exogenous processes

A key determinant of banks' choices with respect to asset and liability structure is the uncertainty they face with respect to returns on loans and liquid assets, prices of liquid assets and interest rates on long- and short-term debt. We assume that price processes on the asset and liability side are exogenously determined, i.e. there is no relation between banks' choices on the adjustment of asset and liability structures and returns on assets or cost of funding (see Section 2.1 for a discussion).

Specifically, returns on loans and liquid assets for bank j at time t evolve according to the following simple processes:

$$r^L_{j,t} = r^{CB}_t + \mu - \zeta + \eta^{rL}_{j,t} \qquad \text{with} \quad \eta^{rL}_{j,t} \sim \mathcal{N}(0,\, \sigma^2_{rL}) \tag{2}$$

$$r^F_{j,t} = r^{CB}_t + \psi + \eta^{rF}_{j,t} \qquad \text{with} \quad \eta^{rF}_{j,t} \sim \mathcal{N}(0,\, \sigma^2_{rF}) \tag{3}$$

where r^{CB}_t is the interest rate set by the central bank, μ the constant mark-up charged by banks on loans in an oligopolistic market, ζ the expected impairment rate on loans, and $\eta^{rL}_{j,t}$ a conditionally homoskedastic normally, independently and identically distributed (i.i.d.) error with variance σ^2_{rL} that reflects the non-diversifiable component of risk in the loan portfolio. Heterogeneity with respect to banks' returns on loans then comes from the idiosyncrasy of shocks in each period, which can be interpreted as exogenous economic shocks hitting local economies in different ways. For liquid assets, ψ reflects the average risk premium and $\eta^{rF}_{i,t}$ is a normally i.i.d. error with variance σ^2_{rF}. We expect that $(\mu - \zeta) > \psi$ and $\sigma^2_L > \sigma^2_{rF}$, since loans are typically more profitable but also more risky than liquid assets.

The prices of liquid assets are assumed to evolve following a unit root model:

$$\ln P^F_{j,t+1} = \ln P^F_{j,t} + \eta^{pF}_{j,t} \qquad \text{with} \quad \eta^{pF}_{j,t} \sim \mathcal{N}(0,\, \sigma^2_{pF}) \tag{4}$$

The price process for liquid assets is bank-specific, to capture different compositions of the trading book across banks. The shock $\eta^{pF}_{j,t}$ is a conditionally homoskedastic normally i.i.d. error with variance σ^2_{pF} which directly affects banks' asset values, profits, and both capital and liquidity ratios. For the covariance between shocks to asset prices and returns we assume that $\sigma_{rF,pF} = -1$, reflecting the usual inverse relationship between asset prices and returns.

For interest rates on deposits, long-term debt, and short-term debt, we assume:

$$i^D_t = r^{CB}_t + \phi \tag{5}$$

$$i^{LT}_{j,t} = r^{CB}_t + \xi + f(CR_{j,t}) + \eta^{iL}_{j,t} \qquad \text{with} \quad \eta^{iL}_{j,t} \sim \mathcal{N}(0,\, \sigma^2_{iL}) \tag{6}$$

$$i^{ST}_{j,t} = r^{CB}_t + \gamma + g(CR_{j,t}) + \eta^{iS}_{j,t} \qquad \text{with} \quad \eta^{iS}_{j,t} \sim \mathcal{N}(0,\, \sigma^2_{iS}) \tag{7}$$

In line with the sticky nature of deposits, the deposit rate i^D_t depends only on the interest rate set by the central bank and a constant mark-up ϕ, determined in oligopolistic competition among banks. In contrast, interest rates on long-term debt and short-term debt are subject to uncertainty, i.e. conditionally homoskedastic normally i.i.d. shocks in each period. In addition to the general mark-ups ξ and γ, we allow the cost of both long and short-term debt to depend on the bank's capital ratio, captured by the functions $f(CR_{j,t})$ and $g(CR_{j,t})$, respectively. We expect short-term debt to be generally cheaper than long-term debt ($\xi + f(CR_{j,t}) > \gamma + g(CR_{j,t})$), while short-term rates are subject to larger fluctuations ($\sigma^2_{iL} < \sigma^2_{iS}$). Moreover, the distribution for the interest rate on short-term debt includes an event corresponding to a tenfold increase in interest rates, occurring with a one percent probability, which reflects the idea of a possible run on short-term debt.

The exogenous shocks are collected in the vector $\mathbf{H_{j,t}} = (\eta^{rL}_{j,t}, \eta^{rF}_{j,t}, \eta^{pF}_{j,t}\, \eta^{iS}_{j,t}, \eta^{iL}_{j,t}, \eta^{D}_{j,t})$. As mentioned, we assume that the shock variances $\mathbf{\Sigma} = (\sigma^2_{rL}, \sigma^2_{rF}, \sigma^2_{pF}, \sigma^2_{iL}, \sigma^2_{iS}, \sigma^2_{D})$ as well as the parameters μ, ψ, ϕ, ξ, γ, and the functions $f(CR_{j,t})$ and $g(CR_{j,t})$are exogenous financial factors which we estimate directly from the data. In contrast, we estimate banks' expectations with respect to the future impairment rate on loans, captured by ζ, by making use of the model as described in Section 3.2. This captures the idea that expectations with respect to future impairment rates may differ from realized rates in the past, so that it is preferable to infer the value of expected default rates implied by banks' observed lending behavior, rather then using realized (ex-post) impairment rates as a proxy for expectations.

2.4 Choices on the adjustment of assets and liabilities

Besides the evolution of the exogenous stochastic processes described in the previous section, banks' profits in each period depend on the choices they make with respect to the adjustment of assets and liabilities. As mentioned before, banks' choices are entirely based on private considerations, reflecting the positive nature of our model. In particular, banks take decisions in order to maximize the stream of expected future dividends, i.e. shareholder value. At the same time, they want to avoid breaching regulatory requirements or having to raise fresh equity, which gives rise to the model's basic trade-off: while taking more risk allows generating higher expected returns, it comes at the cost of higher uncertainty with respect to solvency or liquidity positions and thus increases the risk of breaching regulatory requirements or having to raise fresh equity. As a result of this trade-off banks may want to hold precautionary capital and liquidity buffers on top of their minimum requirements, where the evolution and the adjustment of these precautionary buffers in response to regulatory or economic shocks is at the core of our interest.

Asset structure We assume that loans are sticky and illiquid assets that evolve according to the following equation:

$$L_{j,t+1} = L_{j,t}(1 - \frac{1}{m^L} + g^L_{j,t}) \qquad \text{with} \quad g^L_{j,t} \in [0, \overline{g^L_t}] \tag{8}$$

with m^L being the average loan maturity and $g^L_{j,t}$ the fraction of new loans being issued in period t. We assume that loans remain in the banks' balance sheet until the original principal is repaid. The amount being repaid in each period is equal to the inverse of the average maturity m^L and constitutes the maximum possible decrease in the stock of loans in period t (assuming $g^L_{j,t} = 0$). On the other side, the maximum increase in the stock of loans is given by $-\frac{1}{m^L} + \overline{g^L_{j,t}}$.

Liquid assets evolve as follows:

$$F_{j,t+1} = F_{j,t}(1 + g^F_{j,t}) \qquad \text{with} \quad g^F_{j,t} \in [\underline{g^F_t}, \overline{g^F_t}] \tag{9}$$

where $g^F_{j,t}$ is the adjustment in liquid assets. By definition, liquid assets can always be sold at prevailing market prices, which is why their adjustment does not depend on their maturity and is hence more flexible than the adjustment of the stock of loans.

When deciding on the adjustment of loans and liquid assets, banks need to consider that loans typically generate higher expected returns (since $(\mu - \zeta) > \psi$) that are, however, also more volatile (since $\sigma^2_L > \sigma^2_{rF}$). Thus, increasing the fraction of loans implies higher expected profitability, but also increases the risk of breaching regulatory capital requirements. At the same time, there is an interaction with the bank's liability structure, at least partly due to regulation. As we will discuss below, reshuffling from loans to liquid assets can help to improve both capital and liquidity ratios, since liquid assets are treated more favourably in both types of regulations. To the extent that constraints on these ratios are binding, liquid assets will have a funding advantage relative to loans, since they require less equity financing (due to the lower risk weights) and can more easily be financed by using cheaper short-term debt (due to the definition of the liquidity ratio). This partly compensates the lower expected returns on liquid assets and makes both types of assets interesting from an investment point of view.

Debt structure Besides equity, banks finance their activities through deposits collected from households and non-financial corporations, long-term debt with maturity m^{LT} and short-term debt that needs to be rolled over in each period. By distinguishing three forms of debt with different characteristics we go beyond the traditional banking literature that often focuses on the transformation of deposits into loans (e.g., Diamond and Dybvig 1983, Diamond and Rajan 2000, 2001, Kashyap et al. 2002). This extension enables us to study the interaction of banks' overall financing choices with asset composition and profitability.

Long-term debt and short-term debt evolve according to the following equations:

$$LT_{j,t+1} = LT_{j,t}(1 - \frac{1}{m^{LT}} + g^{LT}_{j,t}) \qquad \text{with} \quad g^{LT}_{j,t} \in [0, \overline{g^{LT}_t}] \tag{10}$$

$$ST_{j,t+1} = ST_{j,t}(1 + g^{ST}_{j,t}) \qquad \text{with} \quad g^{ST}_{j,t} \in [\underline{g^{ST}_t}, \overline{g^{ST}_t}] \tag{11}$$

with m^{LT} and $g^{LT}_{j,t}$ being the average maturity and the new issuance of long-term debt, and $g^{ST}_{j,t}$ the adjustment in short-term debt. As for loans, using long-term debt introduces a rigidity in banks' balance sheets, with the maximum reduction in long-term debt being limited by the amount arriving at maturity ($\frac{1}{m^{LT}}$). In contrast, short-term debt needs to be rolled over each period and can hence be adjusted more flexibly.

A higher share of long-term debt is associated with higher interest expenses (since $\xi > \gamma$), but provides insurance against future shocks to funding costs and the risk of a run on short-term debt (i.e., a sharp increase in short-term debt rates). Moreover, loans can be financed with short-term debt only to a limited extent, since liquidity requirements limit the amount of maturity transformation that banks can engage in. Hence, if banks want to expand the relatively more profitable loans they need to rely on long-term debt or equity financing.

We assume that deposits from households and non-financial corporations are determined exogenously (see Section 2.1). In particular, the *volume* of deposits is subject to exogenous shocks, to capture the idea that a fraction of depositors may want to extract their money in each period. This is an important source of liquidity risk in the model that bank managers may decide to insure against by holding enough liquid assets to pay them out. Deposits are assumed to evolve according to the simple dynamic equation:

$$D_{j,t+1} = D_{j,t} + \eta^D_{j,t} \qquad \text{with} \quad \eta^D_{j,t} \sim \mathcal{N}(0, \sigma^2_D) \tag{12}$$

where $\eta^D_{j,t}$ is an normally i.i.d. distributed idiosyncratic shock with variance σ^2_D. The existence of the shocks $\eta^D_{j,t}$ reflects the risk of a run on deposits and forms part of the motivation for liquidity regulation in our model (besides the possibility of rollover problems for short-term debt). As such, our model relates to the classical banking literature cited above, in which fragile deposits give rise to potential liquidity problems for the bank.

2.5 The profit function and budget constraint

Bank profits at time $t+1$ depend on a set of exogenous parameters (r_t^{CB}, μ, ψ, ϕ, ξ, γ), the expected impairment rate on loans (ζ), the realization of the shocks $\mathbf{H_{j,t}}$, and banks' choices $\mathbf{\Gamma_{j,t}}$. End-of-period profits of bank j can be written as:

$$\begin{aligned}\Pi_{j,t+1} = \; & \underbrace{r^L_{j,t+1} L_{j,t+1}}_{\text{return on loans}} + \underbrace{r^F_{j,t+1} F_{j,t+1} + \eta^{pF}_{j,t} F_{j,t}}_{\text{return on liquid assets}} \\ & - \underbrace{(r^{CB}_{t+1} + \xi) LT_{j,t} (1 - \frac{1}{m^{LT}})}_{\text{cost of existing long-term debt}} - \underbrace{i^{LT}_{j,t+1} g^{LT}_t LT_{j,t}}_{\text{cost of new long-term debt}} \\ & - \underbrace{i^{ST}_{j,t+1} ST_{j,t+1}}_{\text{cost of short-term debt}} - \underbrace{i^{D}_{t+1} D_{j,t+1}}_{\text{cost of deposits}} - \underbrace{exp(\iota_1 + \iota_2 \times log(A_{j,t}))}_{\text{operating cost}}\end{aligned} \tag{13}$$

where the last term is an operating cost associated with banking activity (capturing administrative expenses and amortization of physical capital, net of net fee and commission income) that is defined in exponential terms to allow for possible economies of scale, and the other variables are defined in the previous sections. Banks' income arises from stochastic returns on loans and liquid assets, while changes in liquid asset prices can exert either positive or negative effects on profits. Banks have to pay interest rates on long-term debt, short-term debt and deposits, where all of the short-term debt and the newly issued long-term debt are subject to an interest rate shock.

The budget constraint is defined by banks' balance sheet structure and can be described in terms of the asset evolution equation:

$$A_{j,t+1} = A_{j,t} + \Pi_{j,t+1} - div_{j,t} + \Delta D_{j,t+1} + \Delta LT_{j,t+1} + \Delta ST_{j,t+1} \tag{14}$$

where ΔX_{t+1} is the variation in variable X between beginning and end of period ($\Delta X_{j,t+1} = X_{j,t+1} - X_{j,t}$). The equation ensures that the balance sheet identity is met in each period, since changes in assets are determined by the sum of retained earnings and changes in debt, i.e. changes in assets are equal to changes in aggregate liabilities.[8]

[8] In practice, to ensure that the balance sheet identity holds at each point in time, one of the variables on the asset or liability side needs to be treated as a residual, the evolution of which is implied by the evolution of the other variables. For the solution of the model, we treat liquid assets as the residual variable. In particular, the model specification allows to trivially recover the amount of next-period liquid assets $F_{j,t+1}$ as the difference between end-of-period total assets and loans: $F_{j,t+1} = A_{j,t+1} - L_{j,t+1}$, where end-of period total assets and loans are determined as specified in Eqs. 14 and 8, respectively.

2.6 Dynamics of capital and liquidity structures

2.6.1 Capital structure

The focus of our analysis is on how banks' decisions on asset growth, debt issuance, risk taking and payout policy jointly determine the evolution of capital and liquidity structures. Bank equity evolves according to the following equation:

$$E_{j,t+1} = E_{j,t} + \Pi_{j,t+1} - div_{j,t} \tag{15}$$

The equation illustrates that capital can be accumulated by retaining earnings ($div_{j,t} < \Pi_{j,t+1}$) and by raising fresh equity ($div_{j,t} < 0$). Banks' decision to accumulate capital depends on the discount factor β (capturing the impatience of stockholders), the expected return on capital (depending on the choice of the balance sheet structure and the exogenous parameters controlling the profit function), the level of uncertainty about future profits (reflected in the size of the shock variances, and impacting the precautionary motive for capital accumulation), the regulatory costs associated with capital falling below the minimum requirement, and the cost associated with raising equity externally.

The minimum capital requirement is defined in terms of risk-weighted assets, in line with the idea that riskier assets should be subject to higher capital requirements (see Basel Committee on Banking Supervision 2010). In our simplified framework, the evolution of risk weights is defined as follow:

$$RW_{j,t+1} = w^L \frac{L_{j,t+1}}{A_{j,t+1}} + w^F \frac{F_{j,t+1}}{A_{j,t+1}} + w^O A_{j,t+1} \tag{16}$$

where w^L and w^F are the average risk weights associated with loans and liquid assets, and w^O is a risk weight for operational risk that is assumed to be proportional to total assets.[9] As mentioned, we expect loans to be riskier than liquid assets, and hence $w^L > w^F$.

Eqs. 13 to 16 contain the major factors affecting the evolution of the risk-weighted capital ratio, which depends on the realization of the shocks collected in $\mathbf{H_{j,t}}$ and banks' joint decisions with respect to the adjustment of assets and liabilities collected in $\mathbf{\Gamma_{j,t}}$. Specifically, the risk-weighted capital ratio evolves as follows:

$$CR_{j,t+1} = \frac{E_{j,t+1}}{RW_{j,t+1} A_{j,t+1}} \tag{17}$$

The equation illustrates that banks have at least four different modes of adjustment to increase the risk-weighted capital ratio (compare with Adrian and Shin 2010, Admati et al. 2012): (i) by

[9] Risk weights for operational risk are included for the sake of completeness (see Basel Committee on Banking Supervision 2010) and to ensure consistency between the aggregate risk exposure amount generated by our model and that observed in the data.

using new equity (raised in the market or from retained earnings) to buy back debt, while keeping assets constant ($E_t \uparrow$, $A_t \rightarrow$), (ii) by using new equity to fund asset growth, while keeping debt constant ($E_t = A_t > 0$), (iii) by selling assets and using the proceeds to buy back debt, while keeping equity constant ($A_t \downarrow$, $E_t \rightarrow$), and (iv) by reshuffling assets towards less risky activities (thus decreasing average risk weights in the portfolios), while keeping assets and equity constant ($RW_t \downarrow$, $E_t \rightarrow$, $A_t \rightarrow$). Hence, banks have several levers to manage their capital structure, and decisions on these levers are likely to interact with each other. Furthermore, the different modes of adjustment are likely to have different macroeconomic implications. For example, effects on lending and the real economy could be particularly pronounced under modes (iii) and (iv), where banks reduce the amount of loans in order to reduce debt or to invest more funds into less risky assets. A main contribution of our paper is hence to illustrate the importance of the different modes of adjustment under different initial conditions, which should help regulators to gauge the possible impact of proposed policy measures.

2.6.2 Liquidity structure

The end-of-period liquidity ratio is given by:

$$LR_{j,t+1} = \frac{F_{j,t+1}}{w_{ST} \times ST_{j,t+1} + w_D \times D_{j,t+1}} \tag{18}$$

Although simplified, the liquidity requirement in our model resembles the Basel III Liquidity Coverage Ratio (LCR) that is meant to ensure that financial institutions have a sufficient amount of liquid assets to be able to withstand short-term liquidity disruptions.[10] The weights w_{ST} and w_D specify the fraction of the respective liability class that needs to be covered with liquid assets. Deposits are generally more stable than other short-term debt, so that $w_{ST} > w_D$ (since long-term debt has a pre-defined maturity it cannot be withdrawn under stress, so that $w_{LT} = 0$). Similar to the capital ratio, the evolution of the liquidity ratio depends on both banks' adjustment decisions and the realization of the shocks. The formula illustrates that banks have two possibilities to improve their liquidity ratio: (i) by increasing the amount of liquid assets ($F_t \uparrow$); and (ii) by decreasing the amount of short-term debt ($ST_t \downarrow$; recall that deposits are exogenous and hence not a choice variable of the bank). Again, the different modes of adjustment could have different implications from a social perspective, and we will investigate this further in Section 5.

[10] The Basel III Liquidity Coverage Ratio is defined as the ratio between the stock of *High Quality Liquid Assets* and total net cash outflows under stressed conditions over a period of 30 days (see Basel Committee on Banking Supervision 2013 for details).

2.6.3 Capital and liquidity regulation

Finally, the institutional framework is characterised by the presence of minimum risk-weighted capital requirements θ_{CR} and liquidity requirements θ_{LR}. The regulatory requirements are such that $CR_{j,t+1} > \theta_{CR}$ and $LR_{j,t+1} > \theta_{LR}$ $\forall j = 1, ...J$ and $t = 0, ...T - 1$. As specified in Eq. 1, banks face costs Ω and/or Ψ when breaching these regulatory requirements. The introduction of costs associated with the violation of regulatory requirements, in a context with uncertainty and credible liability and asset structures, allows to investigate the role of regulation in the evolution of capital and liquidity profiles. In particular, we test whether and how much regulatory requirements are indeed important determinants of banks' capital and liquidity profiles by estimating the values of Ω and Ψ: a rejection of the null hypothesis of Ω (or Ψ) equal to zero would indicate that minimum requirements are indeed an important factor for banks' decisions on capital and liquidity profiles. In particular, the interplay between profitability, the cost of equity, the level of uncertainty and the costs of breaching regulatory requirements shapes banks' decisions and induces optimal buffers held on top of either minimum requirement in order to insure against possible shocks. Generally, these buffers can be expected to be larger the larger costs of breaching capital and liquidity requirements. Moreover, positive parameter values for Ω and Ψ would be consistent with classical trade-off theories of capital structure, since the cost of breaching regulatory requirements are reminiscent of the bankruptcy cost usually included in such models.

2.7 Banks dynamic programming problem and solution of the model

The evolution of the entire balance sheet structure can be pinned down by means of five state variables, collected in the vector $\mathbf{\Theta_{j,t}} = (CR_{j,t}, CR_{j,t}, E_{j,t}, LA_{j,t}, DL_{j,t})$. The state variables are the capital and liquidity ratios, the level of equity capital, the share of loans in total assets $LA_{j,t} = L_{j,t}/A_{j,t}$, and the share of deposits in total debt $DL_{j,t} = D_{j,t}/(D_{j,t} + LT_{j,t} + ST_{j,t})$. The solution of our model derives banks' optimal decisions $\mathbf{\Gamma_{j,t}}$ for each point of the state space, so that we can disentangle the relevance of different modes of adjustment for different balance sheet conditions.

Besides the state of the system, optimal decisions at each point in time depend on the exogenous financial factors determining the data generating process for the stochastic variables (r_t^{CB}, μ, ψ, ϕ, ξ, γ, $f(CR_{j,t})$, $g(CR_{j,t})$ and $\mathbf{\Sigma}$) and the remaining structural parameters β, Ω, Ψ, Φ_1, Φ_2 and ζ. In each period t, banks start with loans and liquid assets funded by equity, deposits, long-term and short-term debt from time $t-1$, and receive profits from banking activity as described in Eq. 13.

In this set up, the dynamic optimization problem can be written as:

$$V_{j,t}(\mathbf{\Theta_{j,t}}) = \max_{\mathbf{\Gamma_{j,t}}} \Big[div_{j,t} - \Omega \times \mathbb{1}(CR_{j,t+s} < \theta_{CR}) \tag{19}$$

$$-\Psi \times \mathbb{1}(LR_{j,t+s} < \theta_{LR}) - \Phi_1(-div_{j,t+s})^{\Phi_2} \times \mathbb{1}(div_{j,t+s} < 0) + \beta \mathbb{E}_t V_{j,t+1}(\mathbf{\Theta_{j,t+1}}) \Big]$$

subject to the constraints listed in Eqs. (2) to (18) and the definition of the state variables.

The problem cannot be solved analytically. Instead, we derive optimal decisions at each point of the state space via backward induction, using a standard value function iteration approach. That is, we assume that banks will be liquidated in some future period T (we set $T = 100$), paying out the entire equity in that period without taking any other decisions. Given the value function obtained for period T, we can compute optimal decisions in previous periods. In particular, optimal decisions for each point of the state space in period $T - 1$ are determined such that they maximize the value function of the bank. Going back in time, this procedure is repeated until the policy functions converge.[11]

To solve the model we need to discretize the state variables $\mathbf{\Theta_{j,t}}$ and and the choice variables $\mathbf{\Gamma_{j,t}}$, which we do by using an exponential grid for capital and equally spaced grids for the remaining variables (see Appendix Table A.1 for the exact parametrization). To account for the stochastic nature of the model, we take expectations with respect to the shocks on asset returns, cost of funding, and deposit volumes when deriving optimal decisions at each point of the state space. The density functions for the shocks are approximated, following Tauchen (1986), using gaussian quadrature method when performing the numerical integrations. Finally, we use linear interpolations to evaluate next-period's value function for values of the state variables that do not lie on the exogenous predefined grids.

3 Data and estimation strategy

3.1 Data

The data we use to estimate the model includes information on 116 institutions supervised by the European Single Supervisory Mechanism (SSM), covering the quarters from 2014-Q1 to 2016-Q3 and containing very granular balance sheet and income statement information. Descriptive statistics for the data are presented in Table 1, and a description of all variables is available in Appendix Table A.2. Banks in our sample are rather large, with average assets of more than

[11]That is, we solve the model backwards for 100 periods and check that the policy functions have converged, i.e. $||\mathbf{\Gamma_t}(\mathbf{\Theta}) - \mathbf{\Gamma_{t-1}}(\mathbf{\Theta})|| = 0$.

€200 billion, which is in line with their status as SSM significant institutions.[12] As expected, the risk-weighted capital ratio is on average considerably higher than the unweighted capital ratio, reflecting the average ratio of risk-weighted assets to assets of 45 percent. We report two different values for the liquidity ratio: the first one is the actual Basel III Liquidity Coverage Ratio (LCR) as reported by the banks, while the second is a proxy variable that we calculate in order to match the definition of the liquidity ratio in our model as specified in Eq. 18 (see below for details on the calculation). The distributional characteristics of the two ratios are close to each other, making us confident that we have obtained a good proxy. The table further shows that profitability of European banks is rather low throughout the sample period, with the average quarterly return on assets being only slightly above zero. Finally, it includes a breakdown of assets and liabilities by counterparty: Exposures to corporates and households each account for roughly a quarter of the average bank's assets, with the government sector being the third most important sector. On the liability side, households are by far the largest counterparty, although the fraction of instruments with no specific counterparty (inter alia including debt securities issued, capital and subordinated liabilities, and derivatives) is sizable.

3.2 Estimation strategy

This subsection presents the strategy we use to estimate the structural parameters of the model. The parameters are estimated such that the model describes a number of key features of banks' behavior with respect to the level and the adjustment of their (risk-weighted) capital and liquidity structures. We use a two-step strategy similar to that employed, among others, in Gourinchas and Parker (2002). In the first step, the parameters and functions characterising the exogenous stochastic processes in the model (r_t^{CB}, μ, ψ, ϕ, ξ, γ, $f(CR_{j,t})$, $g(CR_{j,t})$, and $\mathbf{\Sigma}$) are estimated directly from quarterly supervisory data. In the second step, we estimate the remaining structural parameters (β, Φ_1, Φ_2, Ω, Ψ, and ζ) by targeting empirical moments characterizing the dynamic behavior of banks in our data, taking as given the values of the exogenous parameters estimated in the first step.

Exogenous parameters The supervisory data contain detailed balance sheet information that allow us to estimate the parameters characterising the profit function. These are key ingredients to our analysis and reflect on the financial conditions which banks face over the sample period. The data include detailed information on the items that compose the statement of profits and losses, allowing us to back up the spread on loans μ and liquid assets ψ, the

[12] According to the SSM Framework Regulation, all institutions with total assets larger than €30 billion are considered significant. Moreover, institutions are considered significant if their assets exceed 20 percent of national GDP, if they are one of the three largest credit institutions in a country, if they receive direct assistance from the European Stability Mechanism, or if they have significant cross-border activities.

interest rate paid on deposits, short term debt and long-term debt, as well as administrative expenses and the fees and commissions margin (the aggregate of which constitutes the operating cost ι). The estimated exogenous parameters, obtained as median values of the banks in our sample, are reported in Panel A of Table 2. The median value for the interest rate on the ECB's main refinancing operations within our sample period is 0 percent. As expected, loans generate higher returns than liquid assets (before considering the expected impairment rate ζ which we estimate below). To parameterize the functions $f(CR_{j,t})$, $g(CR_{j,t})$, we regress interest rates on short- and long-term debt on bank leverage and report the results in Table 3. The coefficient of interest is insignificant and close to zero in all specifications, indicating that there is no strong relation between interest rates on liabilities and banks' leverage during our sample period.[13] This finding could be due possible distortions arising from the large amount of liquidity in the system, or the possibility that a lot of wholesale funding occurs in the form of collateralized loans for which the riskiness of the counterparty is less important. In any case, since there is no significant relationship in the data we simplify Eqs. 6 and 7 by neglecting the functions $f(CR_{j,t})$ and $g(CR_{j,t})$ and imposing homogeneous mark-ups ξ and γ across banks. Panel A of Table 2 shows that both deposits and short-term debt are considerably cheaper than long-term debt. Moreover, the parameter ι_2 in the function for operating costs is smaller than one, illustrating that there are indeed some economies of scale in operating the bank. Finally, we assume that loans have an average maturity of ten years, reflecting the maturity of a standard mortgage contract, while long-term debt has an average maturity of eight years.

Shock variances Uncertainty plays a crucial role in our model regarding the accumulation of additional buffers on top of minimum capital and liquidity requirements. We estimate the variances of the shocks to the return on loans, the return on liquid assets (and their prices), the cost of financing and the volume of deposits directly from the data. We use a two-step empirical strategy to estimate the variances of these shocks.

In the first step, the aim is to separate the endogenous variation in the measures of return, borrowing costs and deposits from the components that are exogenous to banks' behavior and can hence be interpreted as structural shocks. We construct the shocks $\mathbf{H_{j,t}}$ by regressing the log differences of returns on loans, returns on liquid assets, profits from trading, interest expenses on short-term debt, interest rates on long-term debt, and deposits, respectively, onto observable characteristics. The set of characteristics include the lagged size of the bank (as the logarithm of total assets), and the (lagged) structure of assets (or liabilities, in the equations for $\eta^{iS}_{j,t}$ and $\eta^{iL}_{j,t}$) with respect to the types of instruments held (equity, debt securities, loans and derivatives) and counterparties (central bank, governments, banks, other financial institutions, non-financial corporations and households).

[13] Coefficients remain insignificant when including quadratic terms.

In the second step, we estimate the variances of the shocks using the second order moments for the log differences of returns on loans, returns on liquid assets, profits from trading, interest expenses on short-term debt, interest rates on long-term debt, and deposits, and a GMM strategy, similar to that in Blundell et al. (2016), that allows to deal with the structural equations describing the evolution of rate of returns, costs of financing, and deposits presented in Section 2.7. The standard deviations of the shocks derived as described above are reported in Table 2, Panel B. As expected, returns on loans are more volatile than returns on liquid assets. Moreover, the cost of long-term debt fluctuates less than the cost of short-term debt. Finally, fluctuations in deposits can be sizable, with a standard deviation of 3.1 percent.

Regulatory requirements In order to calculate risk-weighted capital ratios we need to obtain risk weights for loans and liquid assets, as well as risk charges for operational risk. We calibrate the model based on median values observed in the actual data, which are reported in Panel C of Table 2. Moreover, the liquidity ratio defined in the Eq. 18 requires the specification of weights on short-term debt and deposits. In line with Basel Committee on Banking Supervision (2013), we require that the entire short-term debt and five percent of deposits from households and non-financial corporations need to be included in the denominator of the liquidity ratio (i.e., $w^{ST} = 1$ and $w^D = 0.05$).

Finally, we need to specify regulatory requirements on both capital and liquidity ratios. The capital requirement of 12 percent reflects average minimum Pillar 1, Pillar 2, and combined buffer requirements for the SSM significant institutions in our sample.[14] For the liquidity ratio, we need to translate requirements on the Basel III Liquidity Coverage Ratio (LCR) into requirements on our simple liquidity ratio as defined above. We do this by comparing, for the banks in our sample, the level of our liquidity ratio (median of 1.22, see Table 1) with the level of the actual LCR as observed in the supervisory data (mean of 1.33). By dividing 1.22 by 1.33 we obtain a factor of approximately 0.9, which—if applied to the final LCR requirement of 1.0—yields a minimum requirement of 0.9 on our liquidity ratio.

Structural parameters estimation Given the exogenous parameters reported in Table 2, we use a Simulated Method of Moments approach to estimate the remaining structural parameters of the model, i.e. the discount factor β, the regulatory costs Ω and Ψ related to the violation of capital and liquidity requirements, the parameters of the convex costs associated with raising

[14]The minimum Pillar 1 requirement is 8 percent, consisting of 4.5 percent common equity tier 1, 1.5 percent additional tier 1, and 2 percent tier 2 requirements. The average Pillar 2 requirement of SSM significant institutions is 2 percent, the capital conservation buffer requirement for 2016 is 1.5 percent, and additional buffers for systemic institutions are on average 0.3 percent, summing to a total requirement of 11.8 percent, which we round to 12 percent (see European Central Bank 2016). Applicable rates for the Countercyclical Capital Buffer have been 0 percent in all SSM countries throughout our sample period.

fresh equity Φ_1 and Φ_2, and the expected impairment rate on loans ζ. We use the information in the supervisory data to pin down these additional parameters.

The estimation strategy comprises the following steps: first, we solve the model as described in Section 2.7, given the set of exogenous parameters estimated from the data, for a given set of structural parameters. Second, we use the derived policy functions $\mathbf{\Gamma}(\mathbf{\Theta})$ to simulate the dynamic behavior of 2000 banks over 200 periods. In generating this simulated data set, we allow for ex ante heterogeneity in banks' balance sheet structures and size. In particular, banks may differ with respect to the size of their balance sheets, asset composition, amount of equity, deposits, amount of long-term debt and short term debt. Heterogeneity in later periods also depends on the realization of the shocks to asset returns, cost of funding and volume of deposits. We use the simulated profiles for the decisions and state variables to generate a simulated panel data set that matches the composition of the observational data.[15] We target empirical moments that provide a comprehensive representation of both the balance sheet structure in the cross-section and of the dynamic evolution of the variables impacting capital and liquidity profiles. A complete list of the moments that we target, and the description on how they are computed, is reported in the Appendix, Table A.3.

Third, we repeat the first two steps to choose a collection of structural parameters (β, Ω, Ψ, Φ_1, Φ_2, ζ) that minimizes a weighted distance between the moments estimated using supervisory data and those estimated using simulated data generated by the structural model. Hence, the structural parameters are jointly pinned down by the observed patterns in the data. However, it is worth highlighting which sources of variation in the data are especially important for the identification of the specific parameter. First, identification of the discount factor relies heavily on the observed levels of the dividend over equity ratio, total assets and equity. Intuitively, a higher (lower) degree of shareholders' impatience increases (decreases) the dividend payout for any given level of profitability, this way reducing (increasing) capital and decreasing (increasing) the ability of banks to finance asset expansion. The costs of breaching the minimum capital and liquidity requirements are mainly identified by the extent of the observed voluntary buffers that banks hold on top of the minimum requirements. Clearly, higher costs would induce, ceteris paribus, a higher incentive to increase the buffers as an insurance against the risk of facing these costs. Moreover, the relation between asset and risk growth helps identifying the cost of breaching minimum capital requirements, with higher costs inducing a stronger risk-weighted capital structure targeting behavior and hence a stronger negative relation between asset and risk growth. The observed relation between asset and capital growth (and asset and liability growth), together with the level of capital and assets, help pinning down the costs of raising external equity. In particular, lower (higher) costs of raising fresh equity in the market will

[15]To avoid that initial conditions matter, we restrict the simulated data to the periods from 150 onwards when comparing simulated and empircal moments.

induce a higher (lower) covariance between capital and asset growth and increase (decrease) the level of capital and assets, for a given level of shareholders' impatience. Finally, the identification of the expected impairment rate on loans relies heavily on the observed median risk weight, with expectations of high future impairment rates inducing a reshuffling from loans to liquid assets and hence a reduction in the median risk weight.

3.3 Capital and liquidity structure regressions

Before moving to the estimation results we illustrate that our data is comparable to (though more granular than) data sets used in previous studies. To do this, we estimate standard capital and liquidity structure regressions of the following form:

$$CR_{jct} = \alpha_c + \alpha_t + \beta X_{jct} + \epsilon_{jct} \tag{20}$$

$$LR_{jct} = \alpha_c + \alpha_t + \beta X_{jct} + \epsilon_{jct} \tag{21}$$

The dependent variable is either the risk-weighted or the unweighted capital ratio or the liquidity ratio. Explanatory variables are summarized in the vector X_{jct} and include various balance sheet and income statement variables. Further, time and country fixed effects account for unobserved heterogeneity across countries and over time. Standard errors are clustered at the bank level to account for heteroscedasticity and serial correlation of error terms.

Estimation results for Eqs. 20 and 21 are presented in Table 4. In line with previous evidence (see, e.g., Berger et al. 2008, Flannery and Rangan 2008, Gropp and Heider 2010), we find that size is negatively related to risk-weighted and unweighted capital ratios and liqudity ratios, while the relation with profitability tends to be positive (Titman and Wessels 1988, Rajan and Zingales 1995, Frank and Goyal 2009 find similar evidence for non-financial corporations).[16] Not surprisingly, the amount of liquid assets is the most important determinant for our proxy of the liquidity ratio, while deposits exhibit a negative sign, which is expected given that they increase the denominator of the ratio. Interestingly, our results also illustrate that the riskiness of bank assets is a strong predictor of capital ratios. As expected, higher average risk weights (mechanically) decrease risk-weighted capital ratios as they inflate the amount of risk-weighted assets included in the denominator (see columns 1-2). However, there is a positive relation between average risk weights and unweighted capital ratios, suggesting that banks with more risky assets compensate this by maintaining higher unweighted capital ratios (see columns 3-4).

[16] The negative coefficient on size may reflect both arguments according to which larger firms tend to be better diversified, reducing the probability of failure and allowing them to operate with lower capital and liquidity buffers, and too-big-too-fail considerations by which large banks do not fully internalize the costs of bankruptcy and hence opt for lower buffers. The positive coefficient on profitability in the capital regressions is consistent with the pecking order theory, according to which firms will prefer internal funding over issuing debt (see Myers and Majluf 1984).

This illustrates that asset and liability structures are likely to interact with each other and justifies our efforts to investigate the determinants of banks' joint decisions on these variables.

4 Main results

4.1 Estimation results

Panel A of Table 5 shows estimation results for the structural parameters of our model. The estimated value of 0.986 for the quarterly discount factor is standard and corresponds to an annual cost of equity of roughly 6 percent.[17] The cost of breaching regulatory capital or liquidity requirements are 46 and 28 percent of total capital, respectively. Using these values, the model delivers median capital and liquidity ratios that get close to the ones observed in the data. This provides evidence that regulation plays a crucial role in determining the levels of observed capital and liquidity ratios and provides an explanation for the extent of buffer held on top of the minimum requirements: facing shocks to future profitability or liquidity profiles, banks find it optimal to insure themselves against the risk of breaching the regulatory requirement by keeping sufficiently large voluntary buffers (compare with Brunnermeier and Sannikov 2014 and Valencia 2014). The estimated cost of breaching liquidity requirements is considerably lower than the one for breaching capital requirements. This illustrates that liquidity requirements are perceived to be less binding than capital requirements, or—in other words—banks expect a less severe supervisory reaction when they breach liquidity requirements, compared with capital requirements. This feature is consistent with the rationale of the Liquidity Coverage Ratio, which is meant to be breached in times of financial stress (see Basel Committee on Banking Supervision 2013).

The cost of raising equity can be interpreted as a fraction of the capital raised; the estimated parameters for Φ_1 and Φ_2 imply a convex relationship between the cost of raising fresh equity and the amount being raised. The magnitude of the parameters is such that raising equity is relatively costly, so that banks make use of this measure only in exceptional circumstances (in the absence of policy changes, less than one percent of the banks in our sample raise fresh equity in each period). The expected impairment rate on loans equals 0.110 percent, which is very close to the realized impairment rate of 0.118 percent that we observe in the data. This suggests that banks base their expectations on future impairments on realized impairments in the past. Considering this impairment rate, loans still provide higher expected returns than liquid assets, since $\mu - \zeta > \psi$, as expected.

[17] The quarterly discount factor (DF) of 0.986 corresponds to an annual DF of 0.945, which is converted into the cost of equity (COE) according to the following formula: $COE = \frac{1}{DF} - 1$.

4.2 Evolution of balance sheets

Overall, using the estimated structural parameters the model succeeds well in matching the static moments reported in Panel B of Table 5. Both capital and liquidity ratios are slightly lower than in the supervisory data, where a possible reason for this is the existence of additional supervisory guidance on top of requirements that may induce banks to hold larger voluntary buffers than predicted by our model.[18] Moreover, the model does a good job in replicating the observed evolution of the dimensions that compose the banks' balance sheet and determine the adjustment of the risk-weighted capital structures and liquidity profiles (see β coefficients in Panel B). The co-movements between key variables affecting capital and liquidity ratios in the actual and simulated data are also shown in Figure 3, where the sample is restricted to observations where the quarterly change in the respective variable is smaller than 20 percent. In this restricted sample that accounts for outliers the fit between our model predictions and adjustments observed in the actual data is particularly good, as illustrated by the linear fits for the actual data (blue line) and the simulated data (red line) which overlap to a large extent.

Both the actual data and the predictions generated by our model confirm the findings of Adrian and Shin (2014), with a strong co-movement between asset growth and liability growth. This illustrates that banks tend to leverage down (up) by selling assets to buy back debt (funding asset growth with new debt, see Panel A). Capital, on the other hand, is relatively 'sticky': even though there is a slightly positive relationship between asset growth and changes in capital (suggesting that part of the asset growth is funded by retained earnings) the relationship in Panel B is much less obvious and flatter than the one in Panel A. Interestingly, Panel C shows a negative relationship between changes in assets and changes in risk weights. This suggests that either an asset expansion is associated with reshuffling of the portfolio towards safer assets (associated with lower risk weights), or that an increase in risk weights is associated with an asset contraction, where both scenarios are consistent with banks targeting a risk-weighted capital ratio. Assuming that a higher Value-at-Risk (VaR) is associated with higher risk weights, such behaviour is also consistent with the VaR rule of equity management and the procyclicality of leverage documented by Adrian and Shin (2014). Panels D illustrates that there is no strong relation between changes in capital and changes in liabilities, while Panel E shows that the relation between changes in liabilities and changes in risk is similar to the one between changes in assets and changes in risk, which is not surprising given the strong correlation between movements in assets and liabilities. Finally, Panel F shows the positive correlation between

[18] In the SSM area, so called Pillar II guidance is stacked on top of minimum requirements. While this bank-specific *guidance* does not constitute a requirement (in contrast to the Pillar II *requirement*), it reflects supervisory expectations with respect to an adequate level of capital and may be converted into a requirement if it is consistently breached by the bank. Hence, banks may be reluctant to operate with capital ratios lower than the guidance, treating it as a 'de facto' requirement and holding voluntary buffers on top of it (see European Central Bank 2016 for further information on the stacking of requirements and guidance in the SSM area).

changes in capital ratios and changes in liquidity ratios.

5 Assessing the impact of regulatory changes or economic shocks

Using the estimated model, we simulate banks' decisions under the actual economic and institutional conditions during our sample period and then conduct three counterfactual simulations to investigate how banks would adjust capital and liquidity structures in response to policy and economic shocks: (i) an increase in minimum capital requirement; (iii) an increase in minimum liquidity requirements; (iii) an increase in the expected impairment rate on loans.

5.1 Increase in capital requirements

5.1.1 Baseline effect

The first policy experiment investigates the consequences of an increase in minimum capital requirements from 12 to 13 percent. Figure 4 reports the evolution of a number of key variables in response to the policy change. Risk-weighted capital ratios increase relatively fast and in proportion with the increase in requirements: one year after the change banks have adapted to their new target ratio, which is about one percentage point higher than before. There is little heterogeneity in the adjustment, with both the 25^{th} and 75^{th} percentile being close to the median adjustment. That is, most banks simply replenish the voluntary buffers they held prior to the change (but go no further), which is in line with recent microeconometric evidence provided by Bahaj and Malherbe (2017) for a granular panel data set covering 18 U.K. banks.

To further validate the predictions of the structural model, we exploit heterogeneous increases in macroprudential buffer requirements faced by the systemically important financial institutions in our sample period. About half the banks in our sample faced, in different periods, an increase in minimum capital requirements. We then estimate a diff-in-diff regression model with multiple treatment periods, controlling for banks fixed effects as well as variables capturing banks' balance sheet structure. We also run a diff-in-diff regression using the counterfactual behavior of banks simulated by the estimated model in the presence and in the absence of the introduction of a one percent increase in minimum capital requirements.[19] The results are reported in Table 6, and indicate that the predictions of our model are in line with the effects of the introduction of additional buffer requirements estimated from the actual data. The 0.62 percentage points increase in risk-weighted capital ratios following the one percentage point increase in buffer

[19]This analysis uses the baseline profiles, simulated by the model in the absence of the policy change, as control group. We restrict the simulated data to five periods before and after the introduction of the policy change.

requirements compares to the effect of 0.39 percentage points increase estimated from the data, and amply falls within its 95 percent confidence interval.

5.1.2 Mode of adjustment

At first glance, the results of this counterfactual experiment seem to justify the assumption of constant voluntary buffers that is often used in studies on the relation between bank capital and lending or other economic outcomes. However, as we will show below, while the adjustment in the *level* of capital ratios is relatively homogeneous, there are substantial differences in *how* banks adjust to the new target ratio, with important consequences for the evolution of loan supply.

Figure 4 shows that all of the adjustment modes discussed in Section 2.4 are reflected in banks' simulated responses. In the short-run, banks move to higher capital ratios by a combination of accumulating additional equity, reducing assets, and reducing asset risk by shifting from loans to liquid assets. For the median bank, equity increases by about 6 percent and remains at higher levels relative to the baseline scenario. The additional accumulation of equity is achieved by lower payout rates in the periods directly following the policy change (as we will show below, some banks also raise fresh equity). Loans are first reduced by up to 0.5 percent for the median bank (and up to 1.9 percent at the 25^{th} percentile) and recover thereafter, for many banks exhibiting a slight increase relative to the baseline three years after the increase in requirements. The intuition for this development is that the additional equity accumulated in response to the policy change represents a relatively stable form of funding, and it is then attractive for banks to invest this stable form of funding into long-term assets which generally offer higher expected returns. Our findings illustrate that the macroeconomic effects of higher capital requirements depend on the time elapsed since the policy change and reconcile two different streams of the literature: on the one hand, the transition to higher capital ratios can be associated with reductions in loan supply, with potentially negative spillover effects for the real economy (see, e.g., Aiyar et al. 2014, Behn et al. 2016b, and Jiménez et al. 2017 for recent evidence using micro-level loan data).[20] On the other hand, in the medium to long-term, better capitalized banks are better able to lend, so that the real effects of higher capital requirements can be positive (see

[20]Compared with previous estimates in the literature, the short-run reduction in loans of 0.5 percent following a 100 basis point increase in capital requirements is at the lower end (e.g., recent empirical estimates by Bahaj and Malherbe 2017 show that the one-year change in loans following a 25 basis point increase in requirements varies between 0 and 0.7 percent, depending on economic conditions). A possible reason for this is that our model abstracts from negative signalling effects that may be associated with cutting back distributions. In the previous financial crisis, many banks kept paying dividends even when facing significant losses, since they were concerned that cutting back distributions could be perceived as a negative signal that would be punished by investors. Consequently, they preferred other modes of adjustments over cutting back distributions, including deleveraging. Introducing such dividend smoothing motives would likely increase the initial lending response in our model.

also Gambacorta and Shin 2016).[21] Overall, the dominant channel for moving to higher capital ratios is to retain earnings, which is consistent with evidence presented by Cohen (2013) for the aftermath of the global financial crisis.

5.1.3 Heterogeneity in adjustment strategies

Besides the observation that all banks tend to accumulate additional equity, the charts in Figure 4 show that there is considerable heterogeneity in banks' responses to the policy change. A main determinant of these heterogenous adjustments is the initial level of bank capitalization. To illustrate this, we allocate the 2000 banks in the simulated data into 50 equal-sized buckets, sorted by the level of the risk-weighted capital ratio at the time of the policy change (i.e., the 40 banks with the lowest capital ratio are in the first bucket, and so on). Figure 5 then shows the median policy-induced change in capital ratios, assets, loans, equity, dividends, and liquidity ratios in each of these 50 buckets. The first panel illustrates that the additional increase in capital ratios due to the policy change does not depend on initial capitalization: all banks increase their target capital ratio by about one percentage point relative to the baseline, except for very well capitalized banks that are less affected by the change. The qualifier *relative to the baseline* is important in this context, since banks that are close to the regulatory minimum aim to increase their capital ratios also in the absence of a policy change. This is illustrated in the first panel of Figure 6, which plots the total change in capital ratios following the increase in requirements for each of the 50 buckets (i.e., comprising both the change induced by the policy change and the change in the baseline scenario). As expected, banks that are closest to the minimum requirement increase capital ratios the most in absolute terms.

While the change in capital ratios relative to the baseline is homogeneous, there is considerable heterogeneity with respect to the adjustment of the underlying components. That is, banks' mode of adjustment in response to the change strongly depends on initial capitalization, with more constrained banks generally using less preferable adjustment strategies. Generally speaking, three different groups of banks can be distinguished. First, the group of banks with initially high capital ratios is only mildly affected by the policy change. Target ratios for these banks increase, but the pressure to adjust quickly is limited since the banks have sufficient buffers on top of minimum requirements. Consequently, these banks move to higher capital ratios by cutting back dividends and retaining additional earnings, which allows them to maintain profitable lending business and does not induce the cost associated with raising external equity (see Figure 5, buckets 35 to 48). Second, banks that are closer to the minimum pay fewer (or no) dividends

[21] Note that 'real effects' in this context refers only to the direct effects of higher capital requirement on lending. A fully-fledged cost-benefit analysis of changes in capital requirements would have to account also for higher resilience and reduced crisis probabilities that are likely to be associated with higher capital ratios (see, e.g., Behn et al. 2016a). Such an analysis is out of scope for this paper.

already in the baseline scenario, since they are operating below their target capital ratios and need to retain earnings in any case. Consequently, these banks can accumulate less additional capital by cutting back dividends. Moreover, they operate closer to the regulatory minimum and hence face higher pressure to improve capital ratios quickly. Consequently, in addition to cutting back dividends these banks reduce the amount of loans, since loans have a relatively high risk weight so that a reduction in their volume is effective in increasing risk-weighted capital ratios. The chart illustrates that the lower the ability to retain additional earnings by reducing the amount of payouts, the higher the need for banks to reduce loans in order to decrease the denominator of the capital ratio (see Figure 5, buckets 8 to 35). Finally, the banks on the very left face the highest pressure to increase capital ratios quickly, since they are closest to the regulatory minimum. These banks cannot retain additional earnings, since they already retain all their earnings in the baseline scenario. Moreover, the amount by which they would have to cut back lending to achieve their target capital ratios is so large that it becomes preferable to raise external equity instead, despite the cost that is associated with doing so. The fresh equity allows them to maintain lending to a certain extent, so that the reduction in loans is less pronounced than for slightly better capitalized banks that do not raise fresh equity (see Figure 5, buckets 1 to 8).[22]

5.1.4 Impact on liquidity profile

Figures 4 and 5 also show that the changes in (risk-weighted) capital structure affect the bank's liquidity position. Initially, the liquidity ratio strongly increases as banks reshuffle from loans to liquid assets. This effect gradually vanishes as adjustments on the asset side reverse. Moreover, reducing assets and accumulating additional equity allows banks to reduce the amount of debt, in particular long-term debt which is now replaced with another form of stable funding. The stronger reduction of long-term debt implies a shortening of the average debt maturity. Overall, three years after the policy change the liquidity ratio for the median bank is still higher than before, in line with the positive relationship between capital and liquidity ratios predicted by our model and observed in the data. However, a number of banks compensate lower risk-taking on the solvency dimension by take more risk on the liquidity dimension, so that the liquidity ratio declines relative to the baseline. Depending on the relative importance of solvency and liquidity risk, this means that the overall balance sheet structure may become more risky for certain types of banks following an increase in capital requirements. However, the decline in liquidity ratios is relatively modest, and in general both asset and liability structure tend to become more stable in response to the policy change. This overall lower risk-taking also reflects

[22] Banks that choose to reduce loans in response to the policy change *partly* replace the foregone lending by investing in liquid assets. As a result, aggregate deleveraging is strongest for those banks, while at the same time liquidity ratios improve the most (see bottom of Figure 5).

into somewhat lower profitability.

5.1.5 Discussion

Overall, results in this subsection show that the macroeconomic effects of changes in capital requirements are likely to depend on banks' initial balance sheet conditions. There are considerable differences between transitory and medium- to long-run effects, with the latter likely to be more positive than the former. Moreover, the illustrated non-linearities in the adjustment functions are important factors to be taken into account when assessing the short-term impact of proposed policy measures. Adjustment strategies involving a reduction in loan supply are arguably least desirable from a social perspective. Interestingly, such undesirable strategies are mostly chosen by banks that are close – but not too close – to the regulatory minimum prior to the policy change. An interpretation of this result is that a bank's lending reaction likely depends on the extent to which it is willing or forced to recapitalize by raising fresh equity in the market. To prevent undesirable adjustments also in the short-run could, a possible option for supervisors could be to provide additional guidance to banks on *how* they should move to higher capital ratios, to make it more preferable for a larger portion of banks to raise external equity rather than cutting back loans.

5.2 Increase in liquidity requirements

5.2.1 Baseline effect

The second policy experiment analyses how banks' adjust their asset and liability structures in response to an increase in the liquidity requirement from 0.9 to 1.0. Results are reported in Figure 7. As in the previous policy experiment, banks adapt relatively quickly: one year after the policy change the median bank has reached its new target liquidity ratio, which is nine percentage points higher than in the baseline scenario. The change is slightly smaller than proportional, which can be explained by the lower cost that is associated with breaching the liquidity requirement and by the greater ex ante variation in liquidity ratios compared with capital ratios. As we will show below, a number of banks with initially high liquidity ratios are not at all affected by the change in requirements, since they already have sufficiently large voluntary buffers on top of minimum requirements (see also the development 25^{th} percentile at the bottom of the chart).

5.2.2 Mode of adjustment and interaction with capital structure

Adjustments occur on both the asset and the liability side, i.e. banks make use of both modes of adjustment discussed in Section 2.4. First, to improve the denominator of the liquidity ratio, many banks tend to replace short-term debt with long-term debt, so that the average maturity of their debt contracts increases and overall debt structure becomes more stable. Second, to improve the numerator of the liquidity ratio, banks tend to increase their holdings of liquid assets. In the absence of further adjustments, such an increase in liquid assets would imply a decrease in the risk-weighted capital ratio, as liquid assets enter the denominator with a positive weight. Since the target capital ratio is not affected by the change in liquidity requirements, banks need to take further adjustments in order to keep the capital ratio relatively constant. The preferred option for many banks is to reduce loans, so that the total amount of assets remains constant while average risk weights decrease. The shift from loans to liquid assets and from short-term debt to long-term debt reduce the bank's profitability, so that the ability to retain earnings is constrained and equity declines relative to the baseline scenario. Moreover, the larger share of less profitable assets also makes it less attractive for banks to use relative stable and expensive equity financing, so that payouts tend to increase. As a result of the reduction in equity financing the return on equity rebounds to a certain extent, following the initial decline in response to the policy change.

The reduction in loan supply in this second counterfactual is more pronounced and also more persistent than the reduction in the first counterfactual. The intuition for this is as follows: in response to the change capital requirements banks accumulate additional equity, and as explained in the previous subsection it is attractive for them to invest this equity into long-term asset that generate relatively high returns, so that loans rebound and the initial reduction is mitigated. In contrast, following the change in liquidity requirements banks need to increase liquid assets. Their preferred form of funding for liquid assets is short-term debt, while using equity is not attractive from an investment point of view. As banks are unwilling to fund the expansion in liquid assets with additional equity, they need to take other compensatory measures in order to prevent a decline in capital ratios, so that they are forced to reduce loans. The reshuffling from loans to liquid assets decreases average asset profitability and thus hampers also the ability to retain additional earnings, which contributes to a decline in equity and further reduces the bank's ability to extend new loans (since less equity is available to fund the loan growth).

Of course, the channel described above depends on our model feature that increases in liquid assets can amplify constraints on the capital dimension (i.e., that liquid assets have positive risk weights). In reality, banks can arguably increase their liquid asset holdings without decreasing the risk-weighted capital ratio, since domestic sovereign assets carry a risk weight of zero percent in many jurisdictions. In this case, the above channel would be mitigated and the resulting reduction in loan supply could be less pronounced. However, in reality banks face requirements also on unweighted capital ratios (from which we abstract in our model for simplicity reasons), and sovereign assets *do* enter the denominator of the unweighted capital ratio in their full amount. Hence, a way to interpret our findings is that the real effects of changes in liquidity requirements are likely to be more pronounced the more banks' are constrained by the unweighted rather than the risk-weighted capital requirement, and the lower the supply of liquid assets with very low or even zero risk weights.

5.2.3 Heterogeneity in adjustment strategies

As for the case of capital requirements, adjustments in response to the change in liquidity requirements are heterogeneous and depend on initial balance sheet conditions. Figure 8 shows that one year after the policy change banks that are initially closer to the minimum requirement exhibit a more pronounced increase in liquidity ratios relative to the baseline scenario, while a number of banks with initially very high liquidity ratios are not at all affected by the change in requirements. This pattern is driven by a stronger increase of liquid asset holdings for initially more constrained banks. In addition, the most constrained banks also reduce short-term debt, to improve the liquidity ratio quickly. They compensate the reduction in short-term debt by retaining additional earnings, so that capital initially increases and the capital ratio improves in lockstep with the liquidity ratio.[23] As described above, this development is reversed over the medium-term, as the lower share of loans reduce bank's ability and willingness to accumulate equity relative to the baseline scenario. In contrast, banks that are initially less constrained by the liquidity requirement prefer to adjust mainly on the asset side, financing the expansion in liquid assets partly with short-term debt and partly with long-term debt, so that the liquidity ratio improves less than for initially more constrained banks.

Overall, the results in this subsection show that also changes in liquidity requirements can have sizable real effects, under the condition that additional holdings of liquid assets make capital requirements more binding. Again, banks' mode of adjustment is highly non-linear and depends on their initial balance sheet structure. Improvements in liquidity ratios tend to come along with initial improvements in capital ratios, in particular if banks compensate a reduction in short-term debt by retaining additional earnings.

[23]The improvement in capital ratios for this group of banks is due to both an increase in equity financing and a reduction in loans. It would have been less pronounced (about half the current magnitude) if the banks had used long-term debt rather than equity to compensate the reduction in short-term debt.

5.3 Increase in loan impairment rate

Besides regulatory requirements we can also study how banks adjust in response to changes in economic conditions. We simulate an economic downturn by implementing a 10 percent increase in the expected impairment rate on loans. Banks' adjustment functions are plotted in Figure 9. The increase in expected impairments reduces profitability and thus banks' ability to accumulate earnings, so that the bank's equity declines relative to the baseline scenario. The lower amount of equity can finance only a lower amount of assets, so that in particular loans are reduced (since they are costly in terms of required equity financing and less profitable than before). A number of banks compensate the reduction in loans by increasing liquid assets, so that liquidity ratios tend to increase, although the reshuffling on the asset side reflects into an increase in the relative importance of short-term debt. Finally, target capital ratios are virtually unaffected by the change in economic conditions. The latter is mainly due to the way in which we proxy the economic downturn, i.e. as a *certain* decrease in expected profitability. One may argue that a recession also implies greater uncertainty, associated with greater variability in expected returns. In this case, banks would react by keeping larger precautionary buffers on top of regulatory requirements.

6 Conclusion

Our paper develops a structural model of bank behaviour that helps to understand how banks adjust their asset and liability structures in response to changes in regulatory capital and liquidity requirements or economic shocks. When deciding on asset and liability structures, bank managers trade off the ability of generating higher expected returns on equity (e.g. associated with higher leverage) against higher risks of breaching regulatory requirements or having to raise fresh equity. The structural nature of our model allows us to provide a possible micro-foundation for observed fluctuations in bank capital and liquidity ratios and lending behaviour, this way providing an insight into the role of capital and liquidity regulation in affecting banks' decisions and financial stability.

Our model illustrates that banks hold voluntary capital and liquidity buffers for precautionary motives, to insure against solvency and liquidity shocks that could push ratios below regulatory requirements. The cost of raising fresh equity are such that banks use this measure only as a last resort, when they need to improve capital ratios quickly, which is consistent with pecking order theory. The preferred mode of adjusting to higher capital requirements is to retain earnings, in line with evidence from the recent financial crisis (see Cohen 2013). For changes in liquidity requirements, banks mainly adjust by increasing their holdings of liquid assets, which can lead to reductions in loan supply if the additional holdings make the banks capital constrained.

Our model features positive medium- to long-run effects of higher capital requirements, while reductions in loan supply occur mainly during the transition phase. The way in which banks adjust to policy changes strongly depends on initial balance sheet conditions, with initially more constrained banks generally using adjustment strategies leading to less preferable short-run effects from a social perspective. Importantly, strategies involving a larger retention of earnings or the issuance of fresh equity allow for a faster accumulation of additional capital, which helps banks to maintain lending in the face of the policy change.

A clear lesson from the model is that supervisors need to have a good understanding of initial balance sheet conditions when deciding about the calibration of possible policy measures. The overall impact of the measures, and in particular the short-term lending reaction (which is often used as a proxy for the potential cost of policy measures) is likely to depend on how binding the constraints are prior to the policy change. Interestingly, the initially most constrained banks are not necessarily the ones that reduce lending the most. As raising fresh equity in the market may help to sustain lending, regulators or supervisors could consider to provide additional guidance on the way in which the transition to higher capital or liquidity ratios in response to a policy change should occur, to avoid adjustment behaviours leading to socially undesirable outcomes.

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Charts and tables

Figure 1:
Balance sheet structure.

The stylized bank balance sheet structure of our model comprises loans and liquid assets on the asset side, and capital, deposits, long-term debt and short-term debt on the liability side. Loans generate returns as specified in Eq. 2 and evolve according to Eq. 8. Liquid assets generate returns as specified in Eq. 3 and are subject to price movements (Eq. 4). They evolve according to Eq. 9. The evolution of capital depends on profits and payouts (Eq. 15), while we assume exogenously determined deposits subject to random shocks (Eq. 12); interest rates on deposits are defined in Eq. 5. Finally, long-term debt and short-term debt evolve according to Eqs. 10 and 11, where banks have to pay interest rates as specified in Eqs. 6 and 7.

Assets	**Liabilities**
$L_{j,t}$, Loans	**$E_{j,t}$, Capital**
– $r^L_{j,t}$, return on loans	– $\Pi_{j,t}$, profits
– m^L, loan maturity	– $div_{j,t}$, dividends
– $g^L_{j,t}$, new loan issuance	
	$D_{j,t}$, Deposits
$F_{j,t}$, Liquid assets	– $i^D_{j,t}$, interest rate on deposits
– $r^F_{j,t}$, return on liquid assets	
– $lnP^F_{j,t}$, liquid asset prices	**$LT_{j,t}$, Long-term debt**
– $g^F_{j,t}$, liquid asset adjustment	– $i^{LT}_{j,t}$, interest rate on long-term debt
	– m^{LT}, long-term debt maturity
	– $g^{LT}_{j,t}$, new long-term debt issuance
	$ST_{j,t}$, Short-term debt
	– $i^{ST}_{j,t}$, interest rate on short-term debt
	– $g^{ST}_{j,t}$, short-term debt adjustment

Figure 2:
Timing of events and decisions.

The figure plots the timing of events and decisions. In each period, banks start with a balance sheet as depicted in Figure 1. They take decisions on the payout policy, the issuance of new loans and new long-term debt, and the adjustment of liquid assets and short-term debt. These decisions, together with the realization of exogenous shocks on asset returns, cost of funding, and the volume of deposits determine the quarterly profits and, consequently, the next-period value of the state of the system.

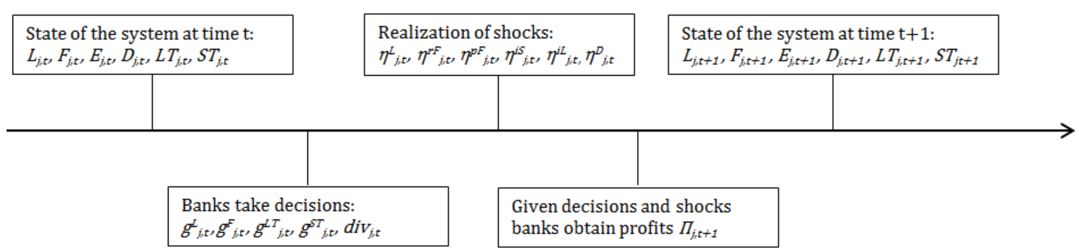

Figure 3:
Quarterly changes in assets, liabilities, capital, and risk weights.

This figure shows the relation between adjustments on banks' asset and liability structures. The sample comprises quarterly data for 116 European banks for the period from 2014-Q1 to 2016-Q3. Growth in assets, liabilities, capital, risk, capital ratios and liquidity ratio are defined as changes in the logarithm of total assets, total debt, capital, and aggregate risk weights, respectively. The blue line is a linear fit of the data, the red line is a linear fit of the same relationship in the simulated data generated by our model. To account for outliers, the sample for these charts is restricted to observations where the quarterly change in the respective variable is smaller than 20 percent.

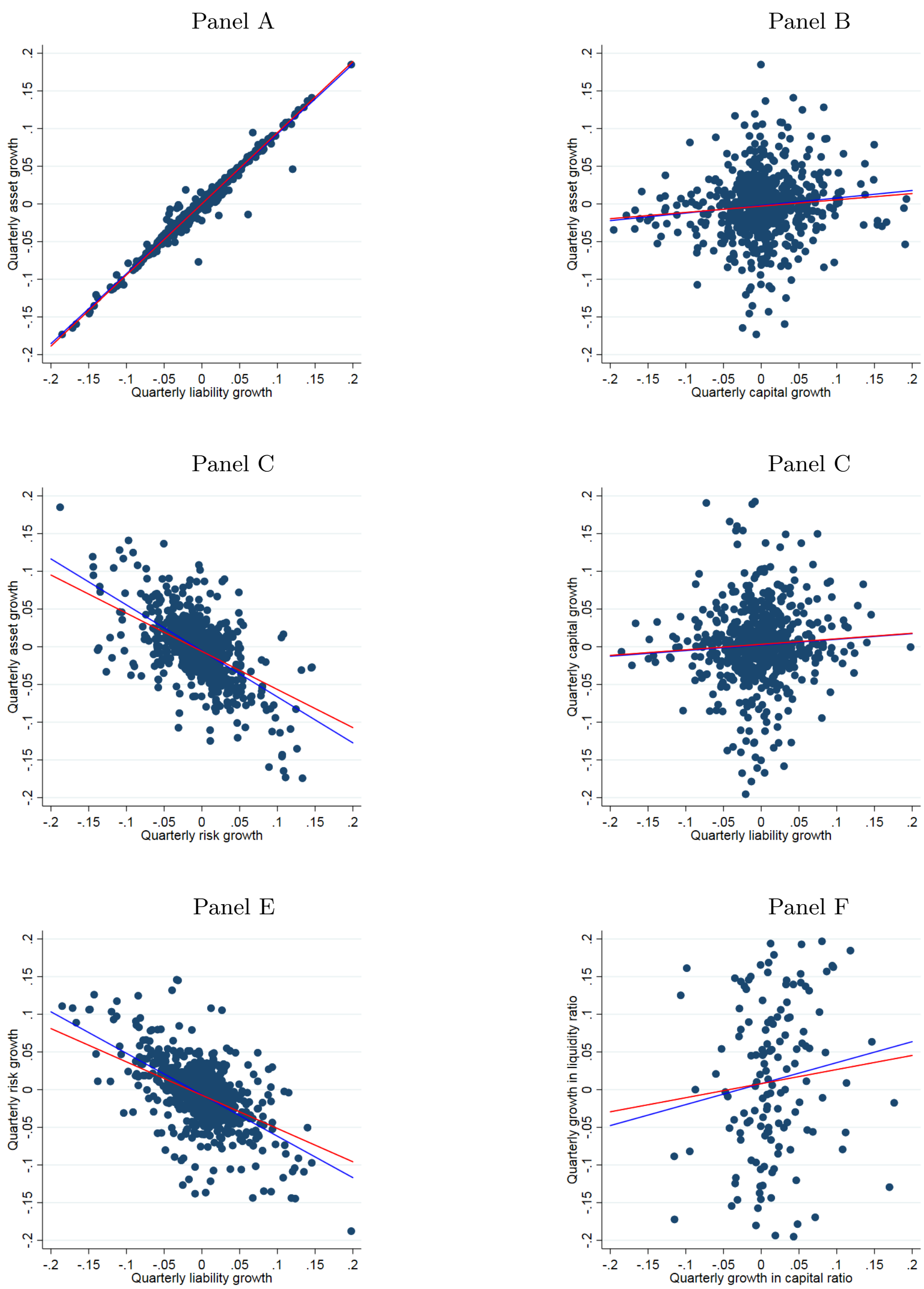

Figure 4:
Increase in minimum capital requirements.

The figure shows simulated counterfactual developments of key variables in response to a one percent increase in minimum capital requirements, relative to developments of these variables without any change in capital requirements. The charts for capital ratios, liquidity ratios, risk weights, and dividends over assets show percentage point differences between the counterfactual and the baseline simulation. The remaining charts show differences in the logarithm of the respective variable between the counterfactual and the baseline simulation; the numbers in these charts can be interpreted as percentage deviations.

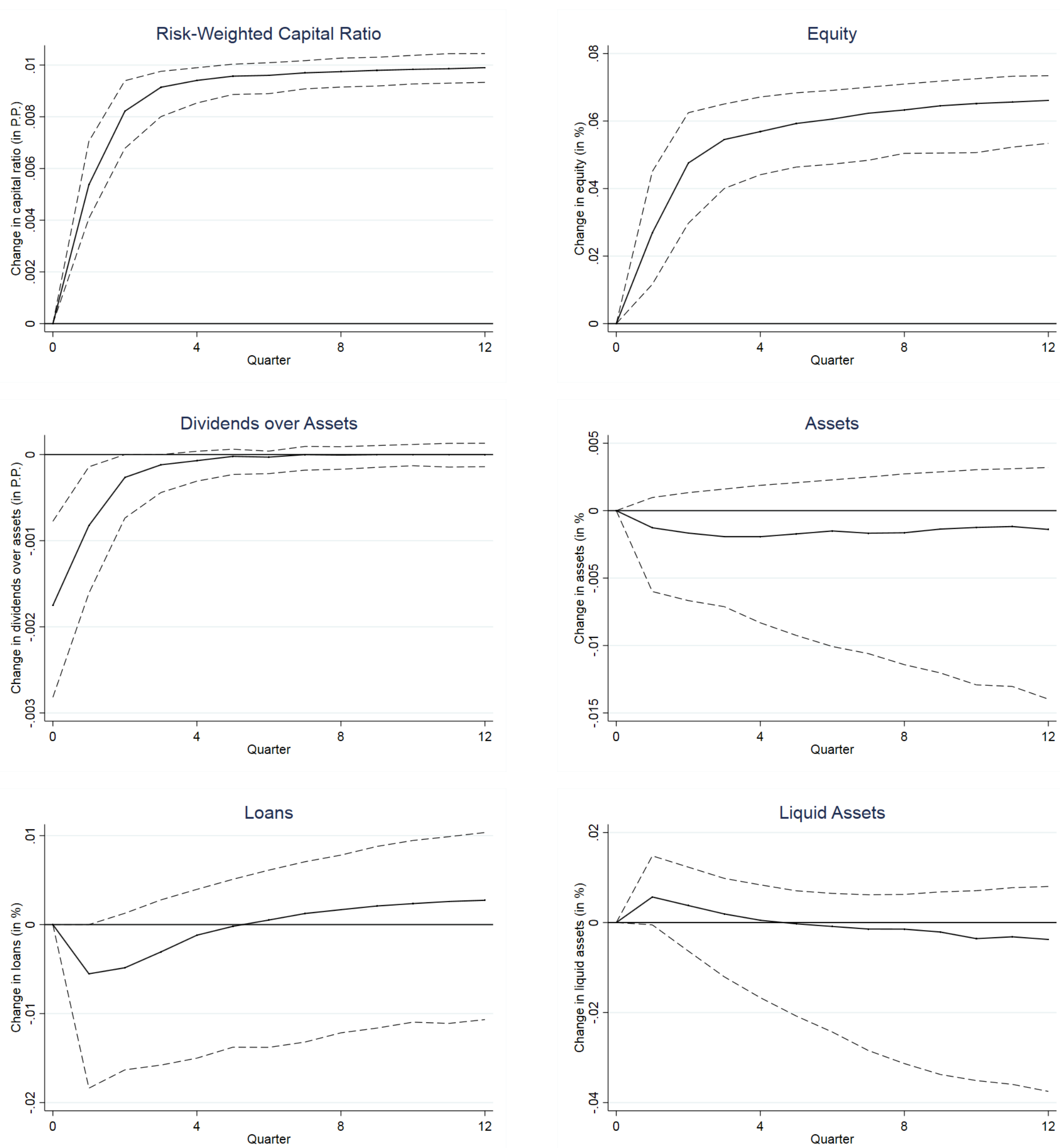

Figure 4 continued...

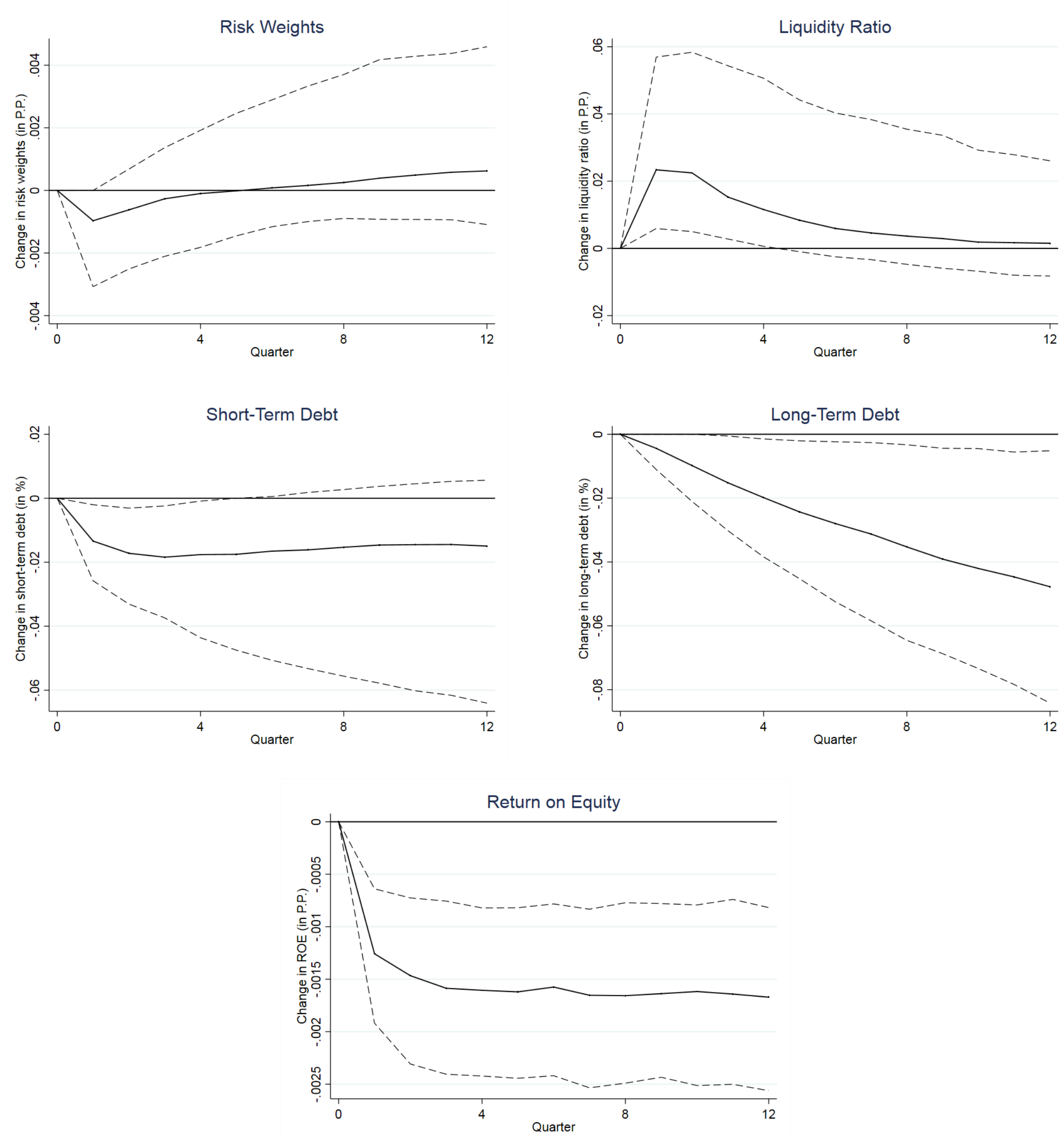

Figure 5:
Heterogenous response to change in capital requirements.

The figure shows the one-year change of key variables in response to a one percent increase in minimum capital requirements, relative to developments of these variables without any change in capital requirements. Banks are sorted into 50 buckets, according to the value of their capital ratio at the time of the policy change (banks with the lowest capital ratio are placed in the first bucket). Each dot corresponds to the median change of the variable in the respective bucket. The red line is a local polynomial smooth, using an Epanechnikov kernel function with bandwidth of 2.5. The charts for capital and liquidity ratios show percentage point differences between the counterfactual and the baseline simulation. The same applies to the chart on dividends over assets, which shows the deviation between counterfactual and baseline in period 170, i.e. directly following the policy change. The remaining charts show differences in the logarithm of the respective variable between the counterfactual and the baseline simulation; the numbers in these charts can be interpreted as percentage deviations.

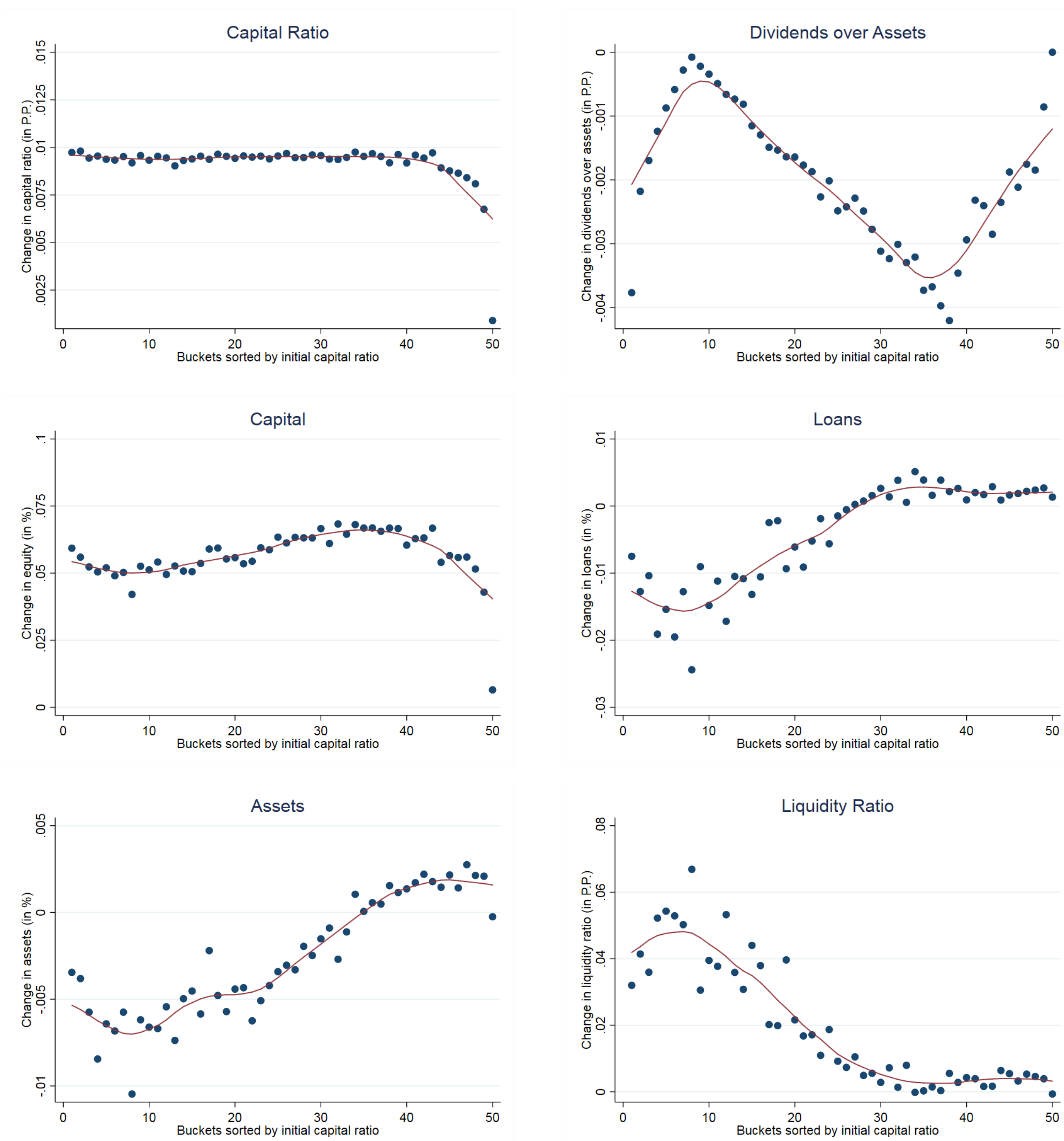

Figure 6:
Heterogenous response to change in capital requirements.

The figure shows the one-year change of key variables in response to a one percent increase in minimum capital requirements, relative to the level of these variables at the time of the policy change. Banks are sorted into 50 buckets, according to the value of their capital ratio at the time of the policy change (banks with the lowest capital ratio are placed in the first bucket). Each dot corresponds to the median change of the variable in the respective bucket. The red line is a local polynomial smooth, using an Epanechnikov kernel function with bandwidth of 2.5. The chart for capital ratios shows the percentage point difference relative to the initial value. The chart for dividends over assets shows the value of this variable in period 170, i.e. directly following the policy change. The remaining charts show differences in the logarithm of the respective variable relative to its initial value; the numbers in these charts can be interpreted as percentage deviations.

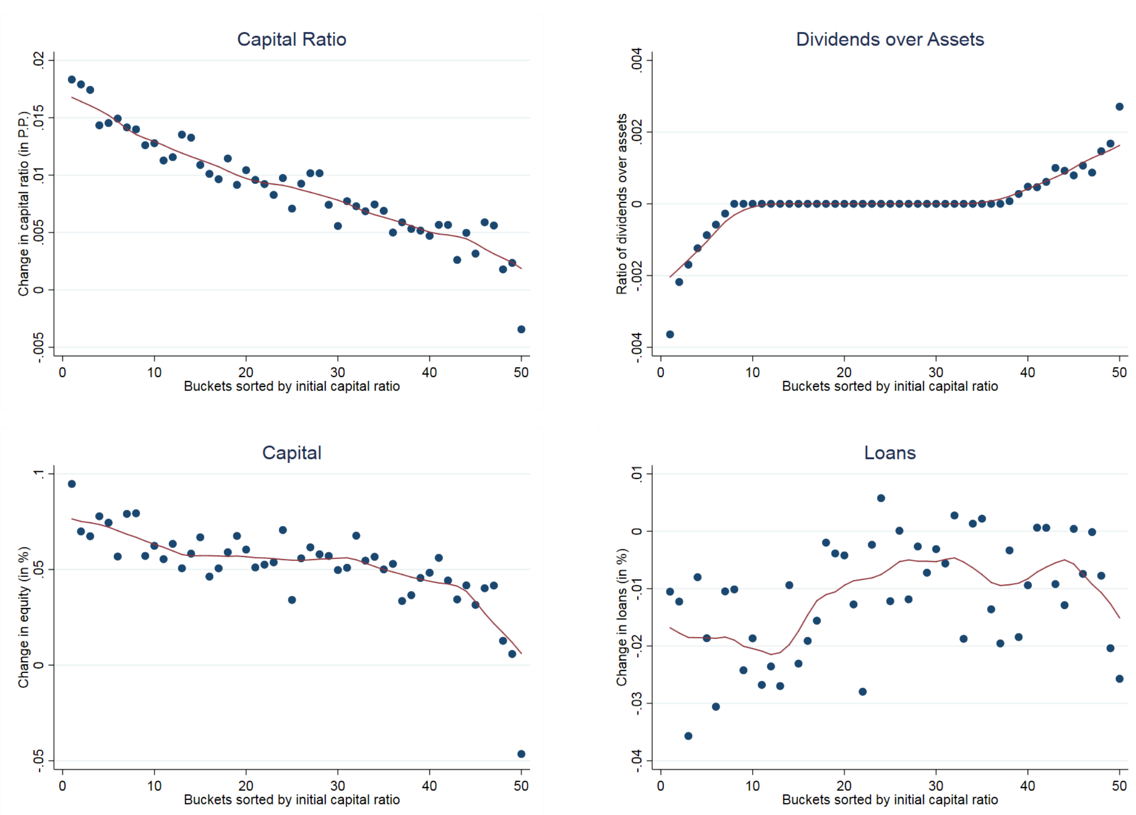

Figure 7:
Increase in minimum liquidity requirements.

The figure shows simulated counterfactual developments of key variables in response to a ten percent increase in minimum liquidity requirements, relative to developments of these variables without any change in liquidity requirements. The charts for capital ratios, liquidity ratios, risk weights, and dividends over assets show percentage point differences between the counterfactual and the baseline simulation. The remaining charts show differences in the logarithm of the respective variable between the counterfactual and the baseline simulation; the numbers in these charts can be interpreted as percentage deviations.

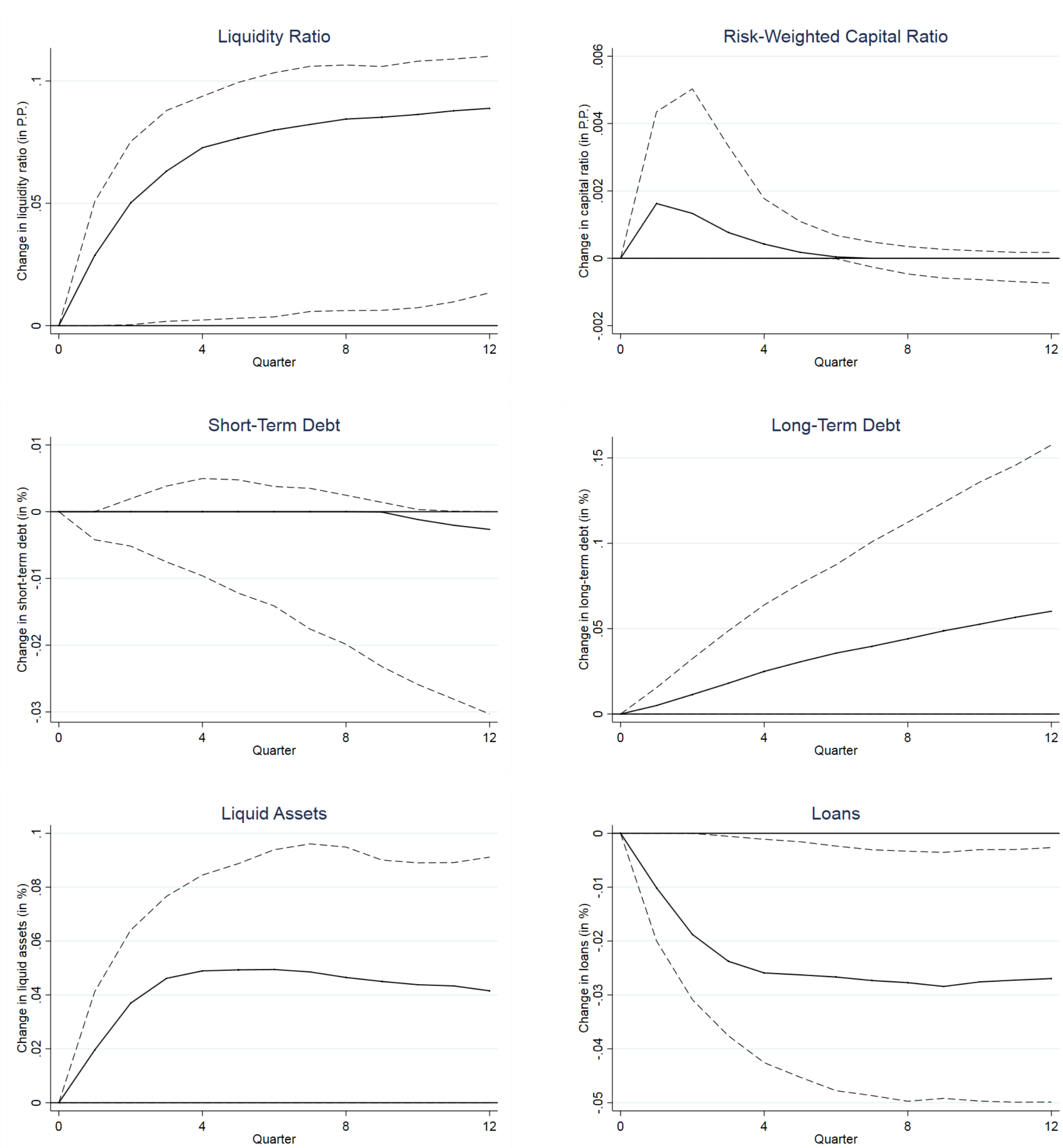

Figure 7 continued...

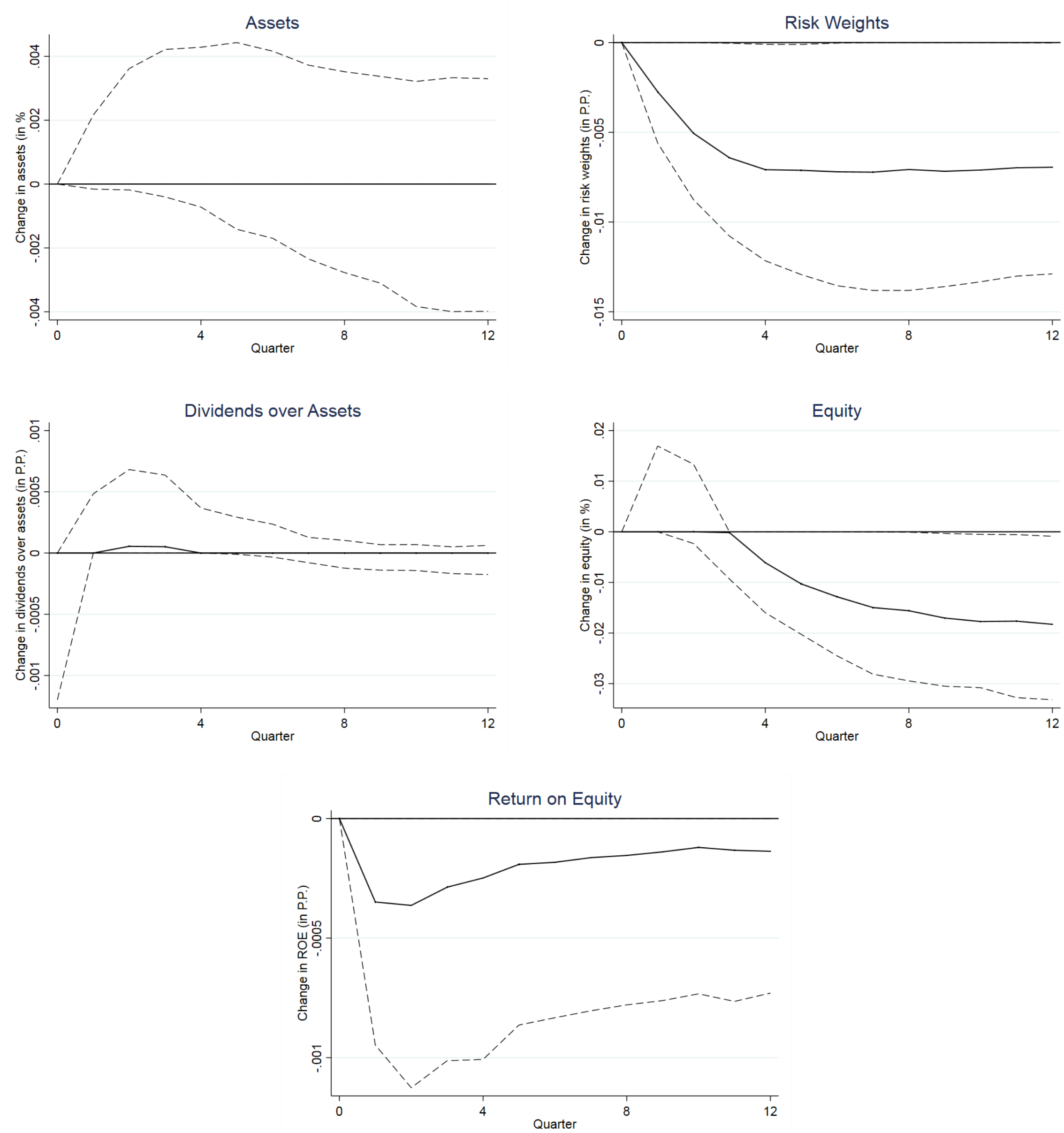

Figure 8:
Heterogenous response to change in liquidity requirements.

The figure shows the one-year change of key variables in response to a ten percent increase in minimum liquidity requirements, relative to developments of these variables without any change in liquidity requirements. Banks are sorted into 50 buckets, according to the value of their liquidity ratio at the time of the policy change (banks with the lowest liquidity ratio are placed in the first bucket). Each dot corresponds to the median change of the variable in the respective bucket. The red line is a local polynomial smooth, using an Epanechnikov kernel function with bandwidth of 2.5. The charts for capital and liquidity ratios show percentage point differences between the counterfactual and the baseline simulation. The remaining charts show differences in the logarithm of the respective variable between the counterfactual and the baseline simulation; the numbers in these charts can be interpreted as percentage deviations.

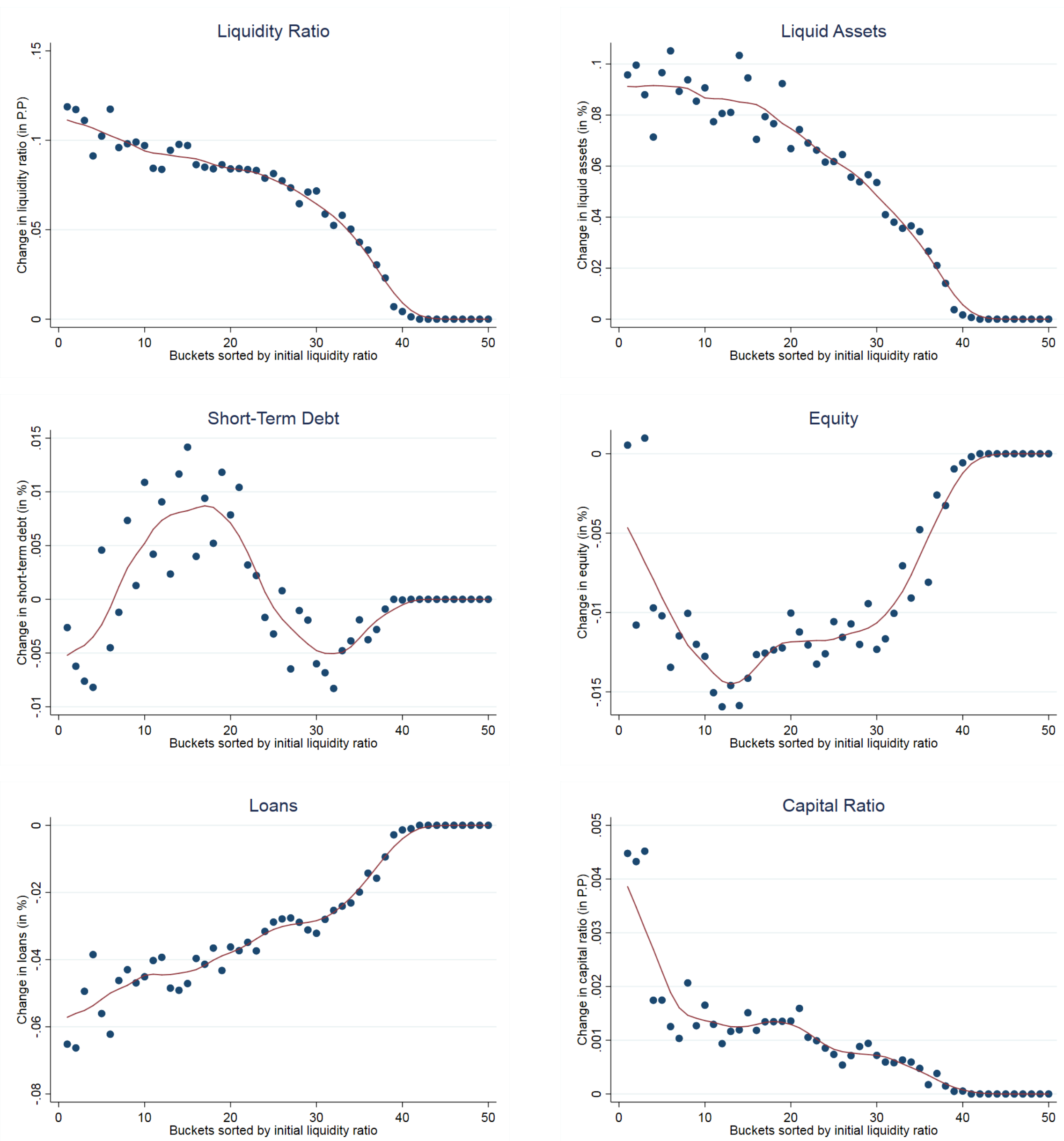

Figure 9:
Increase in expected impairments on loans.

The figure shows simulated counterfactual developments of key variables in response to a ten percent increase in the expected impairment rate on loans, relative to developments of these variables without any change in the impairment rate. The charts for capital ratios, liquidity ratios, risk weights, and dividends over assets show percentage point differences between the counterfactual and the baseline simulation. The remaining charts show differences in the logarithm of the respective variable between the counterfactual and the baseline simulation; the numbers in these charts can be interpreted as percentage deviations.

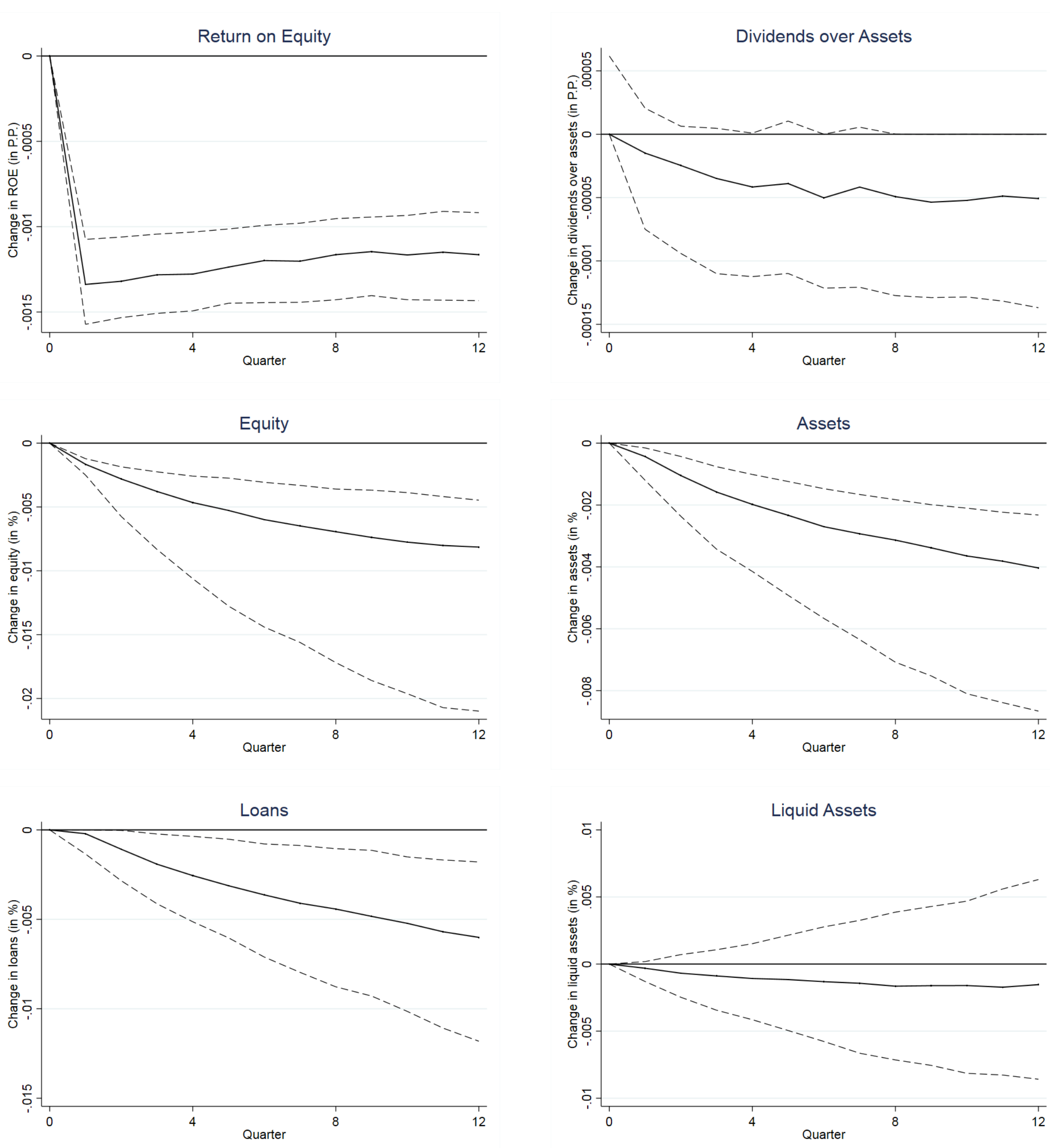

Figure 9 continued...

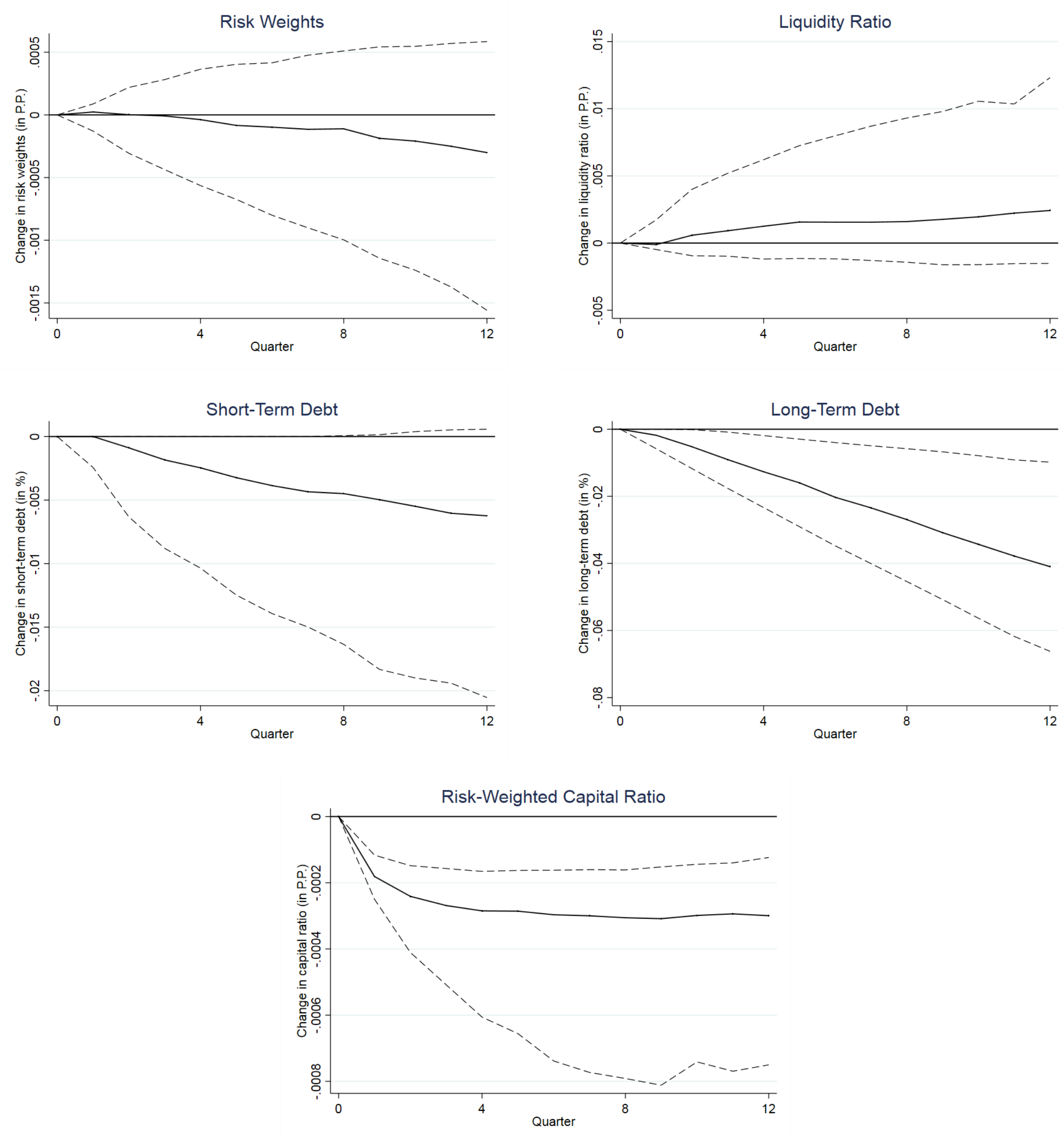

Table 1:
Descriptive statistics

The table provides descriptive statistics for 761 bank-quarter observations, covering a sample of 116 significant institutions supervised by the European Single Supervisory Mechanism (SSM) between 2014-Q3 and 2016-Q3. A description of how the variables are constructed is included in Appendix Table A.2.

	Mean	Median	S.D.	Min.	Max.
Assets (in EUR bn)	221	68	379	2	2,190
Risk-weighted capital ratio	0.168	0.150	0.065	0.070	0.588
Unweighted capital ratio	0.077	0.071	0.039	0.018	0.300
Risk weight	0.450	0.448	0.167	0.047	0.911
Liquidity Ratio (paper proxy)	1.570	1.222	1.059	0.266	7.658
Liquidity Coverage Ratio (LCR)	1.879	1.330	2.128	0.457	26.104
Profit to assets	0.0012	0.0014	0.0030	-0.0185	0.0166
Liquid assets to assets	0.279	0.268	0.109	0.049	0.973
Deposits to liabilities	0.505	0.535	0.235	0.001	0.927
Long-term debt to liabilities	0.272	0.267	0.173	0.012	0.940
Derivatives to assets	0.053	0.027	0.069	0.000	0.422
Counterparty breakdown – asset side					
Central Bank	0.006	0.000	0.013	0.000	0.150
Government	0.155	0.146	0.082	0.013	0.532
Banks	0.091	0.055	0.109	0.000	0.824
Other financial institutions	0.056	0.050	0.044	0.000	0.215
Corporates	0.257	0.255	0.113	0.000	0.637
Households	0.259	0.264	0.159	0.000	0.804
Counterparty breakdown – liability side					
Central Bank	0.048	0.027	0.069	0.000	0.453
Government	0.032	0.024	0.034	0.000	0.261
Banks	0.100	0.063	0.095	0.000	0.520
Other financial institutions	0.097	0.076	0.085	0.000	0.560
Corporates	0.127	0.111	0.088	0.001	0.648
Households	0.336	0.340	0.200	0.000	0.876

Table 2:
Exogenous parameters, shock variances, and regulatory requirements

Panel A shows the exogenous parameters characterizing the profit function, which are directly estimated from our quarterly supervisory data. Numbers are median values for the quarterly supervisory data for 116 banks covering the period from 2014-Q3 to 2016-Q3. A description of how the variables are constructed is included in Appendix Table A.2. Panel B shows estimated shock variances for return, price, interest rate and risk weight variables of our model. The procedure for constructing these shock variances is described in Section 3.2. Panel C shows the minimum requirements on capital and liquidity ratios implemented in our model.

Panel A: Exogenous parameters	
r^{CB}, central bank rate	0.0000
μ, spread on loans	0.0069
ψ, spread on liquid assets	0.0038
ϕ, mark-up on deposits	0.0014
ξ, mark-up on long-term debt	0.0039
γ, mark-up on short-term debt	0.0022
ι_1, where log(operating costs) = $\iota_1 + \iota_2\times$ log(assets)	-4.902
ι_2, where log(operating costs) = $\iota_1 + \iota_2\times$ log(assets)	0.968
m^L, maturity of loans (in quarters)	40
m^{LT}, maturity of long-term debt (in quarters)	32
Panel B: Shock variances	
St. dev. of shocks to return on loans	0.250
St. dev. of shocks to return on liquid assets	0.234
St. dev. of shocks to liquid asset prices	0.000
St. dev. of shocks to interest rates on short-term debt	0.283
St. dev. of shocks to interest rates on long-term debt	0.188
St. dev. of shocks to volume of deposits	0.031
Panel C: Regulatory requirements	
w^L, risk weight on loans	0.555
w^F, risk weight on liquid assets	0.125
w^O, risk weight from operational risk	0.04
w^{ST}, liquidity weight on short-term debt	1
w^D, liquidity weight on deposits	0.05
θ_{RW}, capital requirement	0.12
θ_{LR}, liquidity requirement	0.9

Table 3:
Relation between interest rates and leverage

The table presents results for a regression of short- and long-term interest rates on unweighted capital ratios for our sample of 116 banks between 2014q3 and 2016q3. Standard errors adjusted for clustering at the bank level are reported in parentheses. * indicates statistical significance at the 10 % level, ** at the 5 % level and *** at the 1 % level.

Dependant variable:	Short-term interest rate			Long-term interest rate		
	(1)	(2)	(3)	(4)	(5)	(6)
Unweighted capital ratio	-0.001	-0.001	-0.004	-0.002	-0.002	0.001
	(0.004)	(0.004)	(0.012)	(0.007)	(0.007)	(0.005)
Constant	0.003***			0.004***		
	(0.000)			(0.001)		
Time FE	NO	YES	YES	NO	YES	YES
Bank FE	NO	NO	YES	NO	NO	YES
Observations	690	690	690	706	706	706
R-squared	0.000	0.008	0.032	0.002	0.021	0.146

Table 4:
Standard capital and liquidity structure regressions

The table presents estimation results for Eqs. 20 and 21 for a sample of 116 banks between 2014q3 and 2016q3. Profits, liquid assets, and derivatives are scaled by total assets, deposits and long-term debt are scaled by total liabilities. Risk weights are the ratio of aggregate risk-weighted assets over assets. All columns include asset and liability breakdowns by counterparty as dependent variables (see Table 1). Standard errors adjusted for clustering at the bank level are reported in parentheses. * indicates statistical significance at the 10 % level, ** at the 5 % level and *** at the 1 % level.

Dependant variable:	Risk-weighted capital ratio		Unweighted capital ratio		Liquidity ratio	
	(1)	(2)	(3)	(4)	(5)	(6)
Log(assets)	-0.012***	-0.010**	-0.004**	-0.004*	-0.086***	-0.029
	(0.004)	(0.004)	(0.002)	(0.002)	(0.029)	(0.035)
Profits	3.603***	2.334***	2.119***	1.204***	3.663	8.622
	(0.829)	(0.695)	(0.505)	(0.381)	(7.675)	(7.052)
Liquid assets	0.177***	0.228***	0.079***	0.110***	6.900***	5.916***
	(0.066)	(0.064)	(0.027)	(0.026)	(0.731)	(0.772)
Risk weight	-0.182***	-0.040	0.115***	0.184***	-0.744	-0.101
	(0.054)	(0.034)	(0.032)	(0.025)	(0.574)	(0.449)
Deposits	0.139	0.195	-0.160	-0.142	-0.332	-3.409
	(0.468)	(0.365)	(0.322)	(0.181)	(2.727)	(2.955)
Long-term debt	0.230	0.196	-0.139	-0.170	-0.362	-2.787
	(0.455)	(0.360)	(0.308)	(0.177)	(2.832)	(2.883)
Derivatives	0.031	0.060	-0.046	-0.022	0.029	-2.046
	(0.206)	(0.146)	(0.134)	(0.080)	(1.489)	(1.289)
Asset breakdown	YES	YES	YES	YES	YES	YES
Liability breakdown	YES	YES	YES	YES	YES	YES
Time FE	YES	YES	YES	YES	YES	YES
Country FE	NO	YES	NO	YES	NO	YES
Observations	761	761	761	761	761	761
R-squared	0.434	0.690	0.628	0.810	0.797	0.851

Table 5:
Estimated parameters and target moments

Panel A shows estimation results for the structural parameters of the model. Given the exogenous parameters reported in Table 2, and making use of the information contained in the supervisory data, these parameters are estimated by making use of an indirect inference approach (see Section 3.2 for details). In particular, we first solve the model for a given set of exogenous parameters and use the derived policy functions to simulate the dynamic behavior of 2000 banks over 200 periods. We then use the simulated profiles for the decisions and state variables to generate a simulated panel dataset that matches the composition of the observational data, with the aim of matching moments in the simulated data with moments we observe in the actual data. Target moments observed in the actual data and simulated moments are reported in Panel B.

Panel A: Estimated structural parameters		
β, discount factor	0.986	
Ω, cost of breaching capital requirements (in % of capital)	0.46	
Ψ, cost of breaching liquidity requirements (in % of capital)	0.28	
Φ_1, parameter in cost function for raising equity	1.09	
Φ_2, parameter in cost function for raising equity	1.04	
ζ, expected default rate on loans	0.0011	
Panel B: Target moments	Data	Model
Median risk-weighted capital ratio	0.150	0.146
Median liquidity ratio	1.22	1.17
Median log(assets)	24.9	24.8
Median risk-weighted assets over total assets ratio	0.447	0.432
Average dividend over capital ratio	0.024	0.031
Average profits over total assets ratio	0.0013	0.0019
St. dev. of profits over total assets ratio	0.002	0.001
β_1, where $\Delta log(assets)_{j,t} = \alpha_t + \beta_1 \times \Delta log(capital)_{j,t} + u_{j,t}$	0.15	0.08
β_2, where $\Delta log(capital)_{j,t} = \alpha_t + \beta_2 \times \Delta log(total\ debt)_{j,t} + u_{j,t}$	0.23	0.07
β_3, where $\Delta log(assets)_{j,t} = \alpha_t + \beta_3 \times \Delta log(total\ debt)_{j,t} + u_{j,t}$	0.93	0.94
β_4, where $\Delta log(risk\ weight)_{j,t} = \alpha_t + \beta_4 \times \Delta log(assets)_{j,t} + u_{j,t}$	-0.60	-0.50
β_5, where $\Delta log(risk\ weight)_{j,t} = \alpha_t + \beta_5 \times \Delta log(total\ debt)_{j,t} + u_{j,t}$	-0.56	-0.44
β_6, where $\Delta log(liquidity\ ratio)_{j,t} = \alpha_t + \beta_6 \times \Delta log(risk\ weighted\ capital\ ratio)_{j,t} + u_{j,t}$	0.56	0.18

Table 6:
Capital ratio and changes in requirements

The table reports a comparison between the effects of increased buffer requirements estimated with a diff-in-diff regression in the actual data (Column 1) and in the data simulated by the economic model (Column 2). Both regressions control for banks and time fixed effects. In addition, the model in Column 1 also controls for asset and liability breakdowns by counterparty. Standard errors adjusted for clustering at the bank level are reported in parentheses. * indicates statistical significance at the 10 % level, ** at the 5 % level and *** at the 1 % level.

Dependant variable:	Risk-weighted capital ratio	
	(1)	(2)
	Supervisory data	Simulated data
T*D*Additional Buffers	0.390*	0.619***
	(0.208)	(0.018)
Banks FE	YES	YES
Time FE	YES	YES
Observations	604	40,000

Appendix

Table A.1:
Discretisation of choice and state variables

The table shows parametrisation for banks' choices (Panel A) and the five state variables of our model (Panel B). g^L, g^{LT}, g^{ST}, and div are the fraction of new loans being issued, the fraction of new long-term debt being issued, the adjustment in short-term debt, and the fraction of capital being paid as dividends. The adjustment in liquid assets, g^F, is backed out as a residual (see Section 2.2). CR, LR, E, LA, and DL are the risk-weighted capital ratio, the liquidity ratio, the level of capital, the share of loans in total assets, and the share of deposits in total debt. We use interpolations to evaluate next period's value function for values of the state variables that do not lie on the pre-defined grids in Panel B (see Section 2.7).

Panel A: Choice variables	
g^L	0.0, 0.025, 0.05
g^{LT}	0.0, 0.03125, 0.0625
g^{ST}	-0.05, 0, 0.05
div	-0.1, 0.0, 0.01, 0.02, 0.05, 0.1
Panel B: State variables	
CR	0.12, 0.13, 0.14, 0.15, 0.16, 0.17, 0.18, 0.19, 0.20
LR	0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9
E	exp(20.35), exp(21.78378), exp(22.35), exp(23.78378), exp(24.35)
LA	0.5, 0.6, 0.7, 0.8, 0.9
DL	0.45, 0.50, 0.55, 0.6, 0.65

Table A.2:
Variable descriptions

The table shows how we define the variables used for the estimation of the model. The supervisory COREP/FINREP data is organized by accounting categories. On the asset side, HfT refers to financial assets held for trading, FVA refers to financial assets designated at fair value through profit or loss, AfS refers to available-for-sale financial assets, LR refers to loans and receivables, and HtM refers to held-to-maturity investments. On the liability side, HfT refers to financial liabilities held for trading, FVA refers to financial liabilities designated at fair value through profit or loss, and AmC refers to financial liabilities measured at amortised cost.

Loans	Sum of loans in HfT, FVA, AfS, LR, and HtM portfolios.
Liquid assets	Sum of cash, equity instruments in HfT, FVA, and AfS portfolios, and debt securities in HfT, FVA, AfS, LR, and HtM portfolios.
Equity	Total capital, including Common Equity Tier 1, Additional Tier 1, and Tier 2 instruments.
Deposits	Sum of deposits from households and non-financial corporations in HfT, FVA, and AmC portfolios.
Long-term debt	Sum of debt securities issued, deposits from central banks, and deposits from governments in HfT, FVA, and AmC portfolios.
Short-term debt	Sum of deposits from credit institutions and other financial corporations in HfT, FVA, and AmC portfolios.
Return spread on loans	Ratio of quarterly interest income on loans over loans minus central bank rate.
Return spread on liquid assets	Sum of quarterly dividend income and interest income from debt securities divided by liquid, minus central bank rate .
Mark-up on deposits	Quarterly interest expenditures on deposits from households and non-financial corporations divided by deposits from households and non-financial corporations, minus central bank rate.
Mark-up on long-term debt	Quarterly interest expenditures on debt securities issued divided by debt securities issued, minus central bank rate.
Mark-up on short-term debt	Quarterly interest expenditures on deposits from credit institutions, other financial corporations, central banks, and governments divided by short-term debt, minus central bank rate.
Operating costs	Sum of operating expenses and net fee and commission income, divided by total assets. Operating expenses are defined as the sum of administrative expenses and depreciation. Net fee and commission income is defined as fee and commission income minus fee and commission expenses.

Table A.2 continued...

Risk weight on loans	Risk weighted exposure amounts for credit, counterparty credit and dilution risks divided by loans.
Risk weight on liquid assets	Sum of total risk exposure amount for settlement/delivery, total risk exposure amount for position, foreign exchange and commodities risk, total risk exposure amount for credit valuation adjustment, total risk exposure amount related to large exposures in the trading book, and other risk exposure amounts, divided by liquid assets.
Risk weight from operational risk	Total risk exposure amount for operational risk divided by total assets.
Risk-weighted assets	Total risk exposure amount.
Risk-weighted capital ratio	Capital divided by risk-weighted assets.
Liquidity ratio (paper proxy)	Liquid assets divided by the sum of short-term debt and 5 percent of deposits.
Liquidity ratio (LCR)	Stock of High-Quality Liquid Assets (HQLA) divided by total net cash outflows over the next 30 calendar days (as reported by banks).
Dividend over capital ratio	Quarterly dividend paid (obtained from SNL) divided by capital.
Profits over assets ratio	Quarterly profits divided by total assets.
Derivatives	Sum of derivatives held for trading and for hedge accounting.
Impairments	Quarterly impairments or reversal of impairment on financial assets not measured at fair value through profit or loss.

Table A.3:
Moments matched

The table provides an overview of the moments we target when estimating the structural parameters of the model. Moments 1-8 capture the balance sheet structure profits of the banks in our sample; Moments 9-15 capture the joint dynamic evolution of the dimensions that determine banks' balance sheets and the adjustment of risk-weighted capital structures and liquidity profiles. In the auxiliary regressions, α_t is a time dummy and β is the percentage variation in the variable on the left-hand side that follows a one percent change in the variable on the right-hand side.

1	Median risk-weighted capital ratio
2	Median liquidity ratio
3	Median logarithm of total assets
4	Median risk-weighted assets over total assets ratio
5	Average dividend over capital ratio
6	Average profits over total assets ratio
7	Standard deviation of profits over assets ratio
8	β_1, where $\Delta log(assets)_{j,t} = \alpha_t + \beta_1 \times \Delta log(capital)_{j,t} + u_{j,t}$
9	β_2, where $\Delta log(capital)_{j,t} = \alpha_t + \beta_2 \times \Delta log(total\ debt)_{j,t} + u_{j,t}$
10	β_3, where $\Delta log(assets)_{j,t} = \alpha_t + \beta_3 \times \Delta log(total\ debt)_{j,t} + u_{j,t}$
11	β_4, where $\Delta log(riskweight)_{j,t} = \alpha_t + \beta_4 \times \Delta log(assets)_{j,t} + u_{j,t}$
12	β_5, where $\Delta log(riskweight)_{j,t} = \alpha_t + \beta_5 \times \Delta log(total\ debt)_{j,t} + u_{j,t}$
13	β_6, where $\Delta log(liquiditycoverageratio)_{j,t} = \alpha_t + \beta_6 \times \Delta log(riskweightedcapitalratio)_{j,t} + u_{j,t}$