Rules versus Discretion in Capital Regulation*

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Abstract

We study capital regulation in a dynamic model for bank deposits. Capital regulation addresses banks' incentive for excessive leverage that dilutes depositors, but preserves some dilution to reduce bank defaults. We show theoretically that capital regulation is subject to a time inconsistency problem. In a model with non-maturing deposits where optimal withdrawals make deposits endogenously long-term, we find commitment to have important effects on the optimal level and cyclicality of capital adequacy. Our results call for a systematic framework that limits capital regulators' discretion.

Keywords: capital regulation, time inconsistency, non-maturing deposits, dilution.

JEL codes: G21, G28, E44.

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1 Introduction

Bank capital requirements under Basel III are based on a combination of required capital ratios, conservation capital buffers (CCoB), and countercyclical capital buffers (CCyB). While the former two are formulated as rules, the CCyB can be adjusted dynamically at the discretion of macroprudential regulators. Such discretion on the one hand allows regulators to react promptly to changes in economic outlooks, but on the other hand opens up an important concern from the perspective of policy making, that is, capital regulators are now potentially subject to the classic time inconsistency problem (Committee on the Global Financial System, 2016).[1] Echoing this concern, policy makers have taken some actions to bound their discretion over capital requirements. For instance, the EU Capital Requirements Directive (CRD IV) requires national authorities reducing the CCyB rate to communicate for how long they expect to not increase it again, imposing some constraints on their future selves from tightening up capital requirements too quickly.

Discretion destroys value only when ex-ante optimal policies are time inconsistent (Kydland and Prescott, 1977). Despite the concerns and actions of regulators, whether or how a time inconsistency problem is relevant for capital regulation remains unclear. A clear understanding of these issues is pivotal for policy making. For instance, if keeping a low CCyB rate remains optimal for a long time after a recession hits, the above-mentioned macroprudential "forward guidance" designed by the EU CRD IV is redundant under rational expectation, and might even restrict the flexibility regulators have in response to unforeseen changes during the recovery. In contrast, if keeping a low rate turns out to become quickly suboptimal after it gets reduced today, discretionary regulators will not implement the CCyB in an optimal way, leading to heavy discounts on the ability of such policies to alleviate the distress

[1] See Kowalik (2011), Agur and Sharma (2014), European Systemic Risk Board (2018) for policy discussions about the rule-versus-discretion issue involved in capital regulation. See also discussions in the panel "Banking Regulation: Rules versus Discretion" at Atlanta Fed's 2013 Financial Markets Conference.

at the burst of a recession.

In this paper, we provide the first analysis of the time inconsistency problem associated with bank capital regulation. We show that time inconsistency arises if deposits are subject to default risks and are long-term. About half of US bank deposits are uninsured, and a large proportion of them have a long maturity—they include not only long-term time deposits but also demand deposits without an explicit maturity date that are typically not withdrawn for extended periods. Deposit value reflects risk-adjusted future payments, and therefore, with a long maturity, future leverage of a bank will have an effect on current deposit value as it determines the riskiness of payments not yet received at that point. With this, we show that being able to commit to future leverage matters for today.

Our main analysis is organized into two parts. First, we present a baseline model where deposit maturity is long but fixed. This setup allows maximal transparency to establish theoretically the regulator's time inconsistency problem. Second, we consider an extended model with non-maturing deposits a la Jermann and Xiang (2023) to reflect a key feature of bank deposits, that is, deposit maturity is endogenously determined by withdrawals. We numerically solve the extended model and show how the long-run level (steady states) and dynamics of optimal policies vary with commitment.

Bank deposits provide liquidity benefits. In laissez-faire, banks maximize equity value only and therefore do not internalize that new deposit issuance can dilute the value of legacy deposits by exposing them to a higher default risk. Such an equity-debt conflict implies an incentive for banks to take an leverage that is excessive from a social perspective and has been recognized by policy makers (e.g. Tucker, 2013; Yellen, 2015) and academics (e.g. Admati and Hellwig, 2014) to be an important motivation for capital regulation.[2]

A capital regulator who maximizes social welfare takes into account all stakeholders, i.e.

[2]While we focus on leverage dynamics as they are directly related to capital regulation, banks can dilute legacy deposits also by risk-shifting on the asset side, which further amplifies the equity-debt conflict (Leland, 1998).

the total value of banks and depositors. By correcting the dilution incentive of banks, capital requirements improve the total value that can be generated. However, banks still have the option to default when the equity value becomes too low. Therefore, capital requirements preserve some dilution.

We show theoretically the value of regulatory commitment to future capital requirements. While preserving dilution persuades banks today to default less, it also persuades banks yesterday to default less. This is because, with a long maturity, the deposit value yesterday declines due to the rational expectation of dilution today, effectively enhancing the bank's equity value at that time.. For a regulator who cannot make commitments and thus does not face any constraints inherited from the past, this constitutes a dynamic externality and implies a tendency to adopt an excessively low leverage. To formalize this, we start from the steady state of a Markov-perfect regulator who cannot commit to future policies but allow it to commit in one shot to deposit issuance tomorrow, and we prove that it has an incentive to deviate upward. By committing to an amount of deposits that will become suboptimally high tomorrow, bank defaults today get reduced.

We then go beyond a one-shot commitment and compare a Ramsey regulator who makes full commitments to future policies and a Markov-perfect regulator. We numerically solve an extended setup featuring non-maturing deposits, i.e., deposits have no explicit maturity dates and individual depositors decide whether to withdraw at a cost each period when liquidity shocks realize. We establish two sets of key results.

First, optimal leverage and bank default risk in steady state critically depend on regulatory commitment. Being able to better prevent defaults by using commitment brings a Ramsey regulator a more efficient tradeoff between liquidity and default. We find that the steady state equity ratio under a Ramsey regulator can even be lower than laissez-faire, which is in sharp contrast to typical models of capital requirements. Overall, a regulator who can better prevent default is less afraid to take on leverage. We compare the baseline model with a fixed deposit maturity and the extended model with non-maturing deposits, and we find that endogenous withdrawals can amplify quantitatively the value of commitment because committing to bank leverage tomorrow has an additional effect on deposit withdrawals today.

Second, commitment leads to a stronger countercyclicality in capital requirements. Facing a negative productivity shock, banks have a larger incentive to default. A Ramsey regulator not only loosens capital requirements today but also commits to extend such leniency for a long time. This is useful for resolving bank defaults on impact. In contrast, a Markov-perfect regulator rapidly tightens up its policy as leniency starts to imply too much risk and becomes suboptimal fairly quickly as productivity reverts back. Our result suggests that bounding the ability of regulators to quickly increase the CCyB rate once it has been reduced, as required by e.g. the EU CRD IV, can indeed enhance the effectiveness of the policy tool.

Beyond our main analysis, we explore regulators with partial commitment, finding that committing to either equity values or deposit prices aligns incentives across time, achieving the same steady-state outcomes as full commitment. This highlights that one type of commitment is sufficient to address time inconsistency in capital regulation. Importantly, our findings suggest that a regulator's ability to make credible commitments is more impactful than the specific stakeholders—banks or depositors—to whom those commitments are made.

We also present some empirical evidence about the connection between debt maturity and leverage persistence in the banking sector. Using regression analysis, we find that banks with more financially sophisticated depositors or operating in more competitive local deposit markets exhibit less persistent leverage dynamics. This result suggests that banks engage in dilution. The result aligns with our hypothesis that depositor alertness imposes discipline on banks, effectively shortening deposit maturities and constraining their ability to dilute.

Literature—There is a large literature on macro-finance models that evaluates macroprudential policies, mostly bank capital requirements. Optimal policies have been derived by e.g. Chari and Kehoe (2016), Davydiuk (2017), Bianchi and Mendoza (2018), Malherbe (2020), Schroth (2021), and Van der Ghote (2021). A large number of studies examine the impact of exogenous capital requirement rules, such as Van den Heuvel (2008), Angeloni and Faia (2013), Repullo and Suarez (2013), Mendicino, Nikolov, Suarez and Supera (2018), Begenau (2020), Gertler, Kiyotaki and Prestipino (2020), Corbae and D'Erasmo (2021), Elenev, Landvoigt and Van Nieuwerburgh (2021), Whited, Wu and Xiao (2021), Begenau and Landvoigt (2022), and Xiang (2022). Different from these studies which typically focus on one-period debt and feature distortions from government subsidies, our analysis features long-term debt and the resulting equity-debt conflict, i.e. dilution. Importantly, we also explicitly study a capital regulator's commitment issues.

There is a growing literature that studies the rich dynamics of firms that are financed with long-term debt; see e.g. Gomes, Jermann and Schmid (2016), Crouzet (2017), Admati, DeMarzo, Hellwig and Pfleiderer (2018), Gamda and Saretto (2018), Dangl and Zechner (2021), DeMarzo and He (2021), Chaderina, Weiss and Zechner (2022), Benzoni, Garlappi, Goldstein and Ying (2022), Jungherr and Schott (2022) Jermann and Xiang (2023), and Xiang (2024).[3] While this literature has been focusing on the problem of a borrower, we study a new problem, that is, that of a regulator who cares about the total resources in the economy. Dilution can be good for the regulator to address borrowers' option to default.[4] Quite different from the key insight of existing studies that borrowers' welfare increases if they could commit to dilute less, we highlight that social welfare increases if a Markov-perfect regulator could commit to dilute more.

A large number of studies examine the time inconsistency problem associated with bank

[3] Aguiar, Amador, Hopenhayn and Werning (2019) and Hatchondo, Martinez and Roch (2020) derive optimal paths of long-term debt issuance for a sovereign borrower. Bolton, Li, Wang and Yang (Forthcoming) provide a model of long-term debt that are fully insured.

[4] Donaldson, Gromb and Piacentino (Forthcoming) show that dilution can be good for borrowers to loosen borrowing constraints when there is an asset pledgeability issue.

rescues, including e.g. Acharya and Yorulmazer (2007), Farhi and Tirole (2012), Chari and Kehoe (2016) and Keister (2016). Capital regulation is viewed as a solution to this problem. Kahn and Santos (2015) present a setting where a regulator restricts leverage to address bailouts but ignores how it affects banks' incentive to make efforts. Our contribution is to show that long deposit maturities create a time inconsistency problem for capital regulation.

An unusual property of our model is that the Ramsey allocation features non-stationary Lagrange multipliers together with stationary real variables. This is reminiscent of characterizations in the optimal taxation literature where convergence of multipliers cannot always be established; see e.g. Straub and Werning (2020) or Chien and Wen (2022). Bassetto and Cui (Forthcoming) solve a Ramsey tax problem and find a stationary allocation together with non-stationary multipliers.

The paper proceeds as follows. Section 2 presents our baseline model of capital regulators with and without commitment. Section 3 shows theoretically the value of commitment. Section 4 presents our extended model with non-maturing deposits and numerically solves optimal policies. Section 5 studies capital regulators with partial commitment. Section 6 connects our theory with empirical observations and policy discussions. Section 7 concludes.

2 Model

This section presents our baseline model with a fixed deposit maturity. Section 2.1 describes the laissez-faire economy. Section 2.2 describes the problem of capital regulators. We use lowercase for variables of individual banks and uppercase for aggregate variables.

2.1 Laissez-faire

Time is discrete. All agents are risk-neutral. The economy is populated with a continuum of banks, each of which faces a continuum of depositors and creates value by providing liquidity services. Individual i earns a liquidity benefit of μb_i by holding b_i units of deposits. We assume that μ decreases in the aggregate amount of deposits $B = \int_{i\in[0,1]^2} b_i di$, i.e. $\frac{\partial\mu(B)}{\partial B} < 0$. This assures that a Ramsey regulator in our infinite-horizon setup cannot create an infinitely large liquidity value and is typical for deposit-in-utility models (e.g. Van den Heuvel, 2008). Deposit maturity is $1/\lambda$, that is, each period $\lambda \in (0, 1]$ fraction of deposits get matured.[5]

The assets of a bank generate a per-period profit of $R+z$. We fix aggregate productivity R in our baseline model. z is a zero-mean bank-specific i.i.d. productivity shock with c.d.f. (p.d.f.) $\Phi(z)$ ($\phi(z)$) over support $[-\bar{z}, \bar{z}]$. Taking as given the law of motion for aggregate deposits B, i.e. $B' = \Omega(B)$, an individual bank's equity value and optimal policy in laissez-faire are given by:

$$z + v^e(B, b) = z + \max_{b'} \Bigg\{ R - \lambda b + q(B, b')[b' - (1-\lambda)b] + \frac{1}{r} \left\{ \int_{-v^e(B',b')}^{\bar{z}} [v^e(B', b') + z'] d\Phi(z') \right\} \Bigg\}, \quad (1)$$

where legacy deposits for the bank is $b = \int_{i\in[0,1]} b_i di$ and interest rate is r. Bank takes the deposit pricing schedule $q(B, b')$ as given when choosing b'. Equity value consists of profits $R+z$, repayment to matured deposits λb, proceeds from new deposits $q[b'-(1-\lambda)b]$, and the continuation value which incorporates the bank's default option tomorrow. A bank defaults if its equity value tomorrow goes below zero, i.e. $z' + v^e(B', b') < 0$.

Deposit pricing schedule $q(B, b')$ is pinned down by the zero-profit condition of new depositors. For a non-defaulting bank, the payoff to depositors in the current period consists of liquidity value μb, repayment to matured deposits λb, and the value of unmatured deposits

[5] Both liquidity value and deposit maturity will be determined by the endogenous withdrawals of depositors in our extended model with non-maturing deposits.

$q(1-\lambda)b$. That is, depositors' value is given by:

$$v^b(B,b,q) = [\mu(B) + \lambda + q(1-\lambda)]b.$$

For defaulting banks, our formulation follows Gomes, Jermann and Schmid (2016). Upon default, depositors take over the bank and initiate a restructuring. They first sell off the equity portion to new owners while continuing to hold their deposits. This means that depositors have a claim over the total bank franchise value $z + v^e + v^b$ in defaulting states. However, they incur a dead-weight restructuring loss of ξb. Under this formulation, we do not need to track the cross-sectional distribution of deposits when considering the aggregate economy from the perspective of a regulator. We have, given $B' = \Omega(B)$,

$$\begin{aligned} q(B,b')b' = \frac{1}{r}\Bigg\{ & \int_{-v^e(B',b')}^{\bar{z}} v^b(B',b',q(B',h_b(B',b')))d\Phi(z') \\ & + \int_{-\bar{z}}^{-v^e(B',b')} [z' + v^e(B',b') + v^b(B',b',q(B',h_b(B',b'))) - \xi b']d\Phi(z')\Bigg\}, \end{aligned} \quad (2)$$

where optimal policy $b' = h_b(B,b)$ solves (1). If deposit maturity is long, i.e. $\lambda < 1$, deposit price tomorrow $q(B', h_b(B',b'))$ enters the equation, through which deposit price today will depend on the issuance decision of the bank's tomorrow self.

An equilibrium of the laissez-faire economy is defined as a set of functions for (i) banks' deposit issuance policy $h_b(B,b)$ and equity value $z + v^e(B,b)$ given by (1); (ii) deposit pricing schedule $q(B,b')$ given by (2); (iii) banks' optimal default set $\{z | z + v^e(B,b) < 0\}$; (iv) law of motion for B that is consistent with banks' deposit issuance policy, i.e. $\Omega(B) = h_b(B,B)$.

2.2 Capital regulators

The notation of the laissez-faire economy presented above mostly carries through. As we consider aggregates, we shift to uppercase letters B, Q, L, V^e and V^b. Section 2.2.1 lays out the planning problem of a Ramsey regulator with full commitment. Section 2.2.2 describes the corresponding problem of a Markov-perfect regulator without commitment.

2.2.1 Ramsey regulator

By construction, we can measure social welfare in our model using total resources of the economy. A Ramsey regulator chooses allocations at $t = 0$ to maximize the present value of total resources, taking as given banks' default rule, depositors' zero-profit condition, and an initial B_0. Aggregate resources each period consist of three parts. First, bank assets provide constant profits R with i.i.d. z shocks averaged out. Second, bank deposits provide liquidity value $\mu(B_t)B_t$. Third, a certain fraction of banks default, which produces a total restructuring cost of $\xi B_t \Phi(-V_t^e)$. A Ramsey regulator's problem is thus given by

$$\max_{\{V_t^e, Q_t, B_{t+1}\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \frac{1}{r^t} \left[R + \mu(B_t)B_t - \xi B_t \Phi(-V_t^e)\right],$$

where the optimal choices have to satisfy a series of constraints on equity values

$$V_t^e = R - \lambda B_t + Q_t[B_{t+1} - (1-\lambda)B_t] + \frac{1}{r}\left[\int_{-V_{t+1}^e}^{\bar{z}} (z + V_{t+1}^e) d\Phi(z)\right],$$

and on deposit prices

$$Q_t B_{t+1} = \frac{1}{r}\left[\int_{-V_{t+1}^e}^{\bar{z}} V_{t+1}^b d\Phi(z) + \int_{-\bar{z}}^{-V_{t+1}^e} (z + V_{t+1}^e + V_{t+1}^b - \xi B_{t+1}) d\Phi(z)\right],$$

for all $t \geq 0$, with depositors' value being $V_t^b = [\mu(B_t) + \lambda + (1-\lambda)Q_t]B_t$. In addition, there are two no-Ponzi conditions, i.e. $\lim_{t\to\infty} \frac{B_t}{r^t} = 0$ and $\lim_{t\to\infty} \frac{V_t^e}{r^t} = 0$, and one no-bubble condition, i.e. $\lim_{t\to\infty} \frac{Q_t}{r^t} = 0$.

The following proposition characterizes the solution to this sequential problem by splitting it into a continuation problem and an initial problem. The continuation problem can be represented recursively and leads to definitions of problems with no and partial commitment later.

Proposition 1 *An interior allocation of the Ramsey problem in Section 2.2.1 is identical to that of the following problem. A regulator chooses deposits B', promised equity value $V^{e\prime}$ and promised deposit price Q' at $t \geq 0$ following:*

$$H(B, V^e, Q) = \max_{B', V^{e\prime}, Q'} R + \mu(B)B - \xi B \Phi(-V^e) + \frac{1}{r} H(B', V^{e\prime}, Q'),$$

subject to two promise keeping constraints:

$$V^e = R - \lambda B + Q[B' - (1-\lambda)B] + \frac{1}{r}\left[\int_{-V^{e\prime}}^{\bar{z}} (z' + V^{e\prime}) d\Phi(z')\right], \tag{3}$$

and

$$QB' = \frac{1}{r}\left\{\int_{-V^{e\prime}}^{\bar{z}} V^b(B', Q') d\Phi(z') + \int_{-\bar{z}}^{-V^{e\prime}} [z' + V^{e\prime} + V^b(B', Q') - \xi B'] d\Phi(z')\right\}, \tag{4}$$

where depositors' value is $V^b(B, Q) = [\mu(B) + \lambda + Q(1-\lambda)]B$.

Initially, given B_0, the regulator chooses:

$$\max_{V_0^e, Q_0} H(B_0, V_0^e, Q_0).$$

Choice sets of the regulator are consistent with no-Ponzi and no-bubble conditions.

Proof. See Appendix A.1. ■

In the continuation problem, in addition to the natural state variables B, the Ramsey regulator is bound by two auxiliary state variables—promises made about bank equity value

V^e and deposit price Q. Past promises constrain the regulator's behavior and can support choices that might not be optimal ex post conditional on B only (Kydland and Prescott, 1980). Every period, the Ramsey regulator chooses next period's deposit level B' and makes promises for next period's equity value $V^{e\prime}$ and deposit price Q'.[6] Initially, V_0^e and Q_0 are chosen without being constrained by past promises.

2.2.2 Markov-perfect regulator

Based on Proposition 1, we define the problem of a Markov-perfect regulator as having neither of the two auxiliary state variables in the continuation problem. The Markov-perfect regulator shares the objective function with Ramsey but faces only the natural state variables B. Therefore, it has full discretion regarding what to choose at each point in time. There is no need to split the problem into two given the initial problem and the continuation problem follow the same recursive structure.

Given deposits B, a Markov-perfect regulator solves:

$$H(B) = \max_{B'} \; R + \mu(B)B - \xi B \Phi\left(-V^e(B, B')\right) + \frac{1}{r} H(B'), \tag{5}$$

where bank equity value is given by:

$$\begin{aligned} V^e(B, B') = R - \lambda B + Q(B')[B' - (1-\lambda)B] \\ + \frac{1}{r}\left\{ \int_{-V^e(B', h_B(B'))}^{\bar{z}} [z' + V^e(B', h_B(B'))] d\Phi(z') \right\}, \end{aligned} \tag{6}$$

[6]When we allow shocks to R, e.g. for our model with non-maturing deposits later, these promises will be state-contingent, i.e., the Ramsey regulator picks a separate pair of $\{V^{e\prime}, Q'\}$ for each R' tomorrow in the continuation problem.

and deposit price is given by:

$$Q(B')B' = \frac{1}{r}\Bigg\{ \int_{-V^e(B',h_B(B'))}^{\bar{z}} V^b(B', Q(h_B(B')))d\Phi(z') + \int_{-\bar{z}}^{-V^e(B',h_B(B'))} [z' + V^e(B', h_B(B')) + V^b(B', Q(h_B(B'))) - \xi B']d\Phi(z') \Bigg\}, \quad (7)$$

with depositors' value being $V^b(B,Q) = [\mu(B) + \lambda + Q(1-\lambda)]B$. $B' = h_B(B)$ is the optimal policy that solves (5), which the current regulator takes as given.

3 Capital regulation and commitment

We now demonstrate the time inconsistency problem of capital regulation. Section 3.1 explains how long-term defaultable deposits create a role for capital regulation. Section 3.2 explains why they also imply a time inconsistency problem for a regulator. Section 3.3 contrasts the time inconsistency problem of a regulator against that of banks, the latter of which has been the focus of existing literature.

3.1 Banks' dilution and capital regulation

In laissez-faire, banks maximize their equity value. In typical models of one-period defaultable debt, the equity-value-maximizing objective does not impair social welfare. This is because all legacy debt have to be repaid before banks can issue new debt, who therefore internalize all benefits and costs that result from their issuance decisions. With long-term debt, banks make decisions with the presence of legacy debt, and they do not internalize that issuing new debt will dilute the value of legacy debt by exposing them to additional default risks. This classic equity-debt conflict creates a static externality that impairs social welfare.

More specifically, the derivative of bank's objective in (1) with respect to deposit choice b' is:

$$q(B,b') + [b' - (1-\lambda)b]\frac{\partial q(B,b')}{\partial b'} + [1 - \Phi(-v^e(B',b'))]\,\frac{1}{r}\frac{\partial v^e(B',b')}{\partial b'} = 0. \tag{8}$$

where $B' = \Omega(B)$. The first two terms together capture the marginal benefit from new issuance proceeds today. The third term is the marginal cost reflecting a larger repayment tomorrow.[7] With $q(B,b')$ being typically decreasing in b' in well-behaved models, the second term corresponds to a negative price impact of issuance—that is, a larger repayment pressure leads to a higher default risk tomorrow and thus a lower price $q(B,b')$ today at which *new* deposits $b' - (1-\lambda)b$ can be issued. Importantly, this means that banks do not internalize that *legacy* deposits $(1-\lambda)b$ also bear part of the default risk and encounter a value decline, which is reflected by the dilution term $-(1-\lambda)b\frac{\partial q(B,b')}{\partial b'}$ in (8). Due to this externality, banks have the tendency to issue an amount of deposits that is excessive from the perspective of maximizing social welfare. By doing so, the increased default risk reduces the present value of future payments to legacy deposits, i.e. the debt burden for banks, and benefits equity value.

Proposition 2 connects the problem of a capital regulator with that of laissez-faire banks. While laissez-faire banks maximize equity value v^e (or its monotone transformation $v^e - \xi B\Phi(-v^e)$), a regulator also takes into account the value of legacy deposits V^b. Capital regulation improves social welfare by correcting the equity-value-maximizing objective of banks.[8] Moreover, all regulators share a total-value-maximizing objective after the initial period, and therefore, any potential difference between their steady-state policies reflects

[7]By envelope theorem, we know: $\frac{\partial v^e(B,b)}{\partial b} = -\lambda - (1-\lambda)q(B,h_b(B,b)) < 0$.

[8]In addition, since we have assumed that liquidity value $\mu(B)$ decreases in B in order to bound the problem of a Ramsey regulator, regulators improve welfare also by internalizing that adopting a smaller B improves $\mu(B)$. In Section 4.3, we solve our model and find this channel to play a relatively minor role as regulated economies admit a much larger B than laissez-faire.

only their different degrees of commitment power.

Proposition 2 *In equilibrium, total value created by a Ramsey capital regulator in the continuation problem is*

$$H(B, V^e, Q) = V^e + V^b(B, Q) - \xi B \Phi(-V^e), \tag{9}$$

and total value created by a Markov-perfect capital regulator is

$$H(B) = V^e\left(B, h_B(B)\right) + V^b(B, Q(h_B(B))) - \xi B \Phi\left(-V^e\left(B, h_B(B)\right)\right), \tag{10}$$

where $h_B(B)$ is its policy function.

Proof. See Appendix A.2 ■

3.2 Regulator's time inconsistency problem

Now we describe the tradeoff faced by a regulator and show that optimal capital regulation suffers a time inconsistency problem. Sharing the same objective, a regulator can create a larger total value by committing to deposit issuance that no longer remains optimal as time evolves.

Differentiate the Markov-perfect regulator's objective in (5) with respect to deposit choice B':

$$\left[-(1-\lambda)B\frac{\partial Q(B')}{\partial B'} + \frac{1}{r}\frac{\partial H(B')}{\partial B'}\right]\xi B \phi(-V^e(B, B')) + \frac{1}{r}\frac{\partial H(B')}{\partial B'} = 0. \tag{11}$$

The first term describes how B' reduces default costs today through elevating bank equity value $V(B, B')$. The second term describes how it affects total value tomorrow. The presence of the dilution term $-(1-\lambda)B\frac{\partial Q(B')}{\partial B'}$ reflects that the regulator does not want to fully eliminate dilution. This is because banks have the option to default, and thus diluting banks' debt burden can still be valuable. With $Q(B')$ being typically decreasing in well-behaved models, this term is positive.

While a Markov-perfect regulator eliminates the static externality caused by banks' equity-value-maximizing objective, i.e. dilution is allowed only when it improves total value today, there is still a dynamic externality. This is because allowing dilution can also improve total value yesterday. In particular, the value of legacy deposits yesterday declines when depositors back then rationally expect today's dilution to reduce the expected payment to them, i.e. Q's are intertemporally connected when $\lambda < 1$. The Markov-perfect regulator does not internalize such a positive impact of current dilution on its past self and therefore has the tendency to under-issue relative to social optimum.

Formally, the Markov-perfect regulator's objective described by (5) increases in total value tomorrow $H(B')$ but decreases in deposit price today $Q(B')$.[9] Both terms are forward-looking and take into account the issuance decision of the regulator tomorrow, i.e. $B'' = h_B(B')$. Let's consider an experiment where we give the Markov-perfect regulator a one-shot opportunity today to choose B''. This essentially gives the Markov-perfect regulator some commitment power. According to the envelope theorem, a small deviation to $B'' > h_B(B')$ will affect total value tomorrow only in a second-order way because at $B'' = h_B(B')$ total value tomorrow is already maximized. However, this deviation can reduce deposit price tomorrow when $Q(.)$ is decreasing, which in turn, with $\lambda < 1$, reduces deposit price today in a first-order way. On net, total value today increases. Proposition 3 formalizes this reasoning and establishes the time inconsistency problem of a capital regulator.

Proposition 3 *In an interior steady state, a Markov-perfect regulator improves total value today by committing to a small one-shot deviation to a larger issuance tomorrow if (i) deposit*

[9] Bank equity value in the objective (after plugging (7) into (6) and then simplifying using (10)) can be rewritten as $V^e(B, B') = R - \lambda B - Q(B')(1-\lambda)B + \frac{1}{r}H(B')$. This increases in $H(B')$ and decreases in $Q(B')$.

pricing function is locally downward sloping, i.e. $\frac{\partial Q(B')}{\partial B'}|_{B'=B_{ss}} < 0$ *where subscript ss denotes steady state values and (ii) deposit maturity is long, i.e.* $\lambda < 1$.

Proof. See Appendix A.3. ■

To sum up, committing to a large deposit issuance in the future serves as a useful tool for a regulator to prevent bank defaults today. A regulator with such an ability, e.g. Ramsey, can create liquidity benefits by incurring smaller default costs. This implies a more efficient tradeoff.

3.3 Comparing regulator's and banks' time inconsistencies

It is worth comparing the time inconsistency problem of a capital regulator that we have established in the previous section and the time inconsistency problem of a borrower that has been examined by the existing literature. The latter is sometimes called a "dilution problem" or a "leverage ratchet effect", and it describes how a borrower's lack of commitment impairs its own welfare (e.g. Gomes, Jermann and Schmid, 2016; Admati, DeMarzo, Hellwig and Pfleiderer, 2018). The objective of a capital regulator is different from that of a borrower. Therefore, our investigation of optimal regulation is different from the existing literature.

To recap the time inconsistency of borrowers, banks in our case, let's consider a one-shot commitment opportunity for banks similar to that in Section 3.2 for the Markov-perfect regulator. In steady state, banks issue new deposits every period, i.e. $b' - (1-\lambda)b > 0$. A bank's objective described by (1) today increases in equity value tomorrow $v^e(B', b')$ and deposit price today $q(B, b')$. Both terms are forward-looking and take into expectation the issuance decision of bank tomorrow, i.e. $b'' = h_b(B', b')$. Let's give an individual bank a one-shot opportunity today to choose b''. According to the envelope theorem, a small deviating to $b'' < h_b(B', b')$ will affect equity value tomorrow only in a second-order way because at $b'' = h_b(B', b')$ equity value tomorrow is already maximized. However, this deviation can increase deposit price tomorrow when $q(B', b'')$ is decreasing in b'', which in turn, with $\lambda < 1$, increases deposit price today in a first-order way. On net, equity value today increases. Proposition 4 echoes Proposition 3 and establishes the time inconsistency problem of banks.

Proposition 4 *In an interior steady state, a laissez-faire bank improves equity value today by committing to a small one-shot deviation to a lower issuance tomorrow if (i) deposit pricing function is locally downward sloping, i.e.* $\frac{\partial q(B_{ss}, b')}{\partial b'}|_{b'=B_{ss}} < 0$ *where subscript ss denotes steady state values and (ii) deposit maturity is long, i.e.* $\lambda < 1$.

Proof. See Appendix A.4. ■

Why is an increase in deposit issuance tomorrow good for enhancing equity value today under a Markov-perfect regulator but bad under laissez-faire banks? The difference is driven by the fact that equity value decreases in deposit price conditioning on total value tomorrow (Footnote 9), but increases in deposit price conditioning on equity value tomorrow (Equation (1) when $b' - (1 - \lambda)b > 0$). An increase in issuance tomorrow always reduces the price of long-term deposits today, however, it improves equity value today at the point where total value tomorrow is maximized but reduces equity value today at the point where equity value tomorrow is maximized. Intuitively, to elevate equity value at time t, one should enhance the value of newly issued deposits $B_{t+1} - (1 - \lambda)B_t > 0$. The Markov-perfect regulator at time $t + 1$ protects the value of all deposits B_{t+1}—for the purpose of enhancing equity value at time t, it should instead dilute the value of legacy deposits $(1 - \lambda)B_t$ by choosing a higher B_{t+2}. In contrast, a bank at time $t + 1$ takes into account none of the deposits then existing—for the purpose of enhancing equity value at time t, it should instead protect the value of newly issued deposits $B_{t+1} - (1 - \lambda)B_t$ by choosing a lower B_{t+2}.

4 Optimal policies with non-maturing deposits

In the previous section we demonstrated the value of one-shot commitment. In this section, we numerically solve the optimal policies of Ramsey and Markov-perfect regulators to gauge the effect of full commitment. We do so in an extended model with non-maturing deposits and with aggregate shocks. Our modeling of deposits follows Jermann and Xiang (2023) that captures a key feature of bank deposits that distinguishes them from corporate bonds with fixed maturity. In particular, a major portion of US bank deposits have no explicit maturity dates and depositors withdraw on demand, which implies that the effective deposit maturity is endogenously changing. While we are able to analytically show the value of one-shot commitment in this extended setup similar to Propositions 3 and 4 for our baseline model, we delegate these results to Appendix B in order to focus on the new set of results coming out of model solutions.

Section 4.1 describes laissez-faire, Ramsey- and Markov-perfect-regulated economies. Section 4.2 describes our numerical methods and parameter choices. Section 4.3 compares steady states. Section 4.4 compares impulse responses to a negative aggregate shock.

4.1 Setup

4.1.1 Laissez-faire

The liquidity benefit derived by depositor i with deposits b_i consists of two components. First, as in the baseline model, there is a benefit $\mu(B)$ of holding deposits within the period for day-to-day transactions with $\mu(.)$ being decreasing. Second, at the end of each period a liquidity shock hits, and upon withdrawal a depositor receives benefit ν with c.d.f. (p.d.f.) $F(\nu)$ $(f(\nu))$ over support $[\underline{\nu}, \bar{\nu}]$. This reflects various needs that require cash. Withdrawal incurs a marginal cost of κ. Therefore, depositor i finds it optimal to withdraw the entire b_i

if ν is large enough such that

$$1 + \nu - \kappa \geq q,$$

where the deposit price q equals the risk-adjusted present value of future payments and is thus exactly the opportunity cost of withdrawing.

In this setup, the mass of withdrawing depositors is given by:

$$\lambda(q) = 1 - F(q + \kappa - 1), \tag{12}$$

and the liquidity value per unit of deposits combines holding and expected withdrawing benefits, i.e.

$$L(B, q) = \mu(B) + \int_{q+\kappa-1}^{\bar{\nu}} (\nu - \kappa) dF(\nu). \tag{13}$$

We allow shocks to aggregate productivity, i.e. $R' = (1 - \rho_R)R^* + \rho_R R + \sigma_R \tilde{u}$ where R^* is the average productivity and $\tilde{u} \sim \mathcal{N}(0, 1)$. Given law of motion for B, i.e. $B' = \Omega(R, B)$, and that for R, an individual bank solves

$$\begin{aligned} z + v^e(R, B, b) = z + \max_{b'} \Big\{ & R - \lambda(q(R, B, b'))b + q(R, B, b')\{b' - [1 - \lambda(q(R, B, b'))]b\} \\ & + \frac{1}{r}\mathbf{E}\left\{ \int_{-v^e(R',B',b')}^{\bar{z}} [v^e(R', B', b') + z'] d\Phi(z') \right\} \Big\}, \end{aligned} \tag{14}$$

given

$$\begin{aligned} q(R, B, b')b' = \frac{1}{r}\mathbf{E}\Big\{ & v^b(B', b', q(R', B', h_b(R', B', b'))) \\ & + \int_{-\bar{z}}^{-v^e(R',B',b')} [z' + v^e(R', B', b') - \xi b'] d\Phi(z') \Big\}, \end{aligned}$$

where $v^b(B, b, q) = \{L(B, q) + \lambda(q) + [1 - \lambda(q)]q\}b$; $h_b(R, B, b)$ solves (14); $\lambda(.)$ and $L(.)$ are given by (12) and (13).

An equilibrium of the laissez-faire economy requires that individual banks' optimal deposit issuance policy is consistent with law of motion for aggregate deposits B, i.e. $\Omega(R, B) = h_b(R, B, B)$.

4.1.2 Ramsey regulator

A Ramsey regulator solves

$$\max_{\{V_t^e(R^t), Q_t(R^t), B_{t+1}(R^t)\}_{t=0}^{\infty}} \mathbf{E}_0 \sum_{t=0}^{\infty} \frac{1}{r^t} \left[R_t + L(B_t, Q_t) - \xi B_t \Phi(-V_t^e) \right],$$

subject to for all $t \geq 0$

$$V_t^e = R_t - \lambda(Q_t)B_t + Q_t\{B_{t+1} - [1 - \lambda(Q_t)]B_t\} + \frac{1}{r}\mathbf{E}_t\left[\int_{-V_{t+1}^e}^{\bar{z}} (z + V_{t+1}^e) d\Phi(z)\right],$$
$$Q_t B_{t+1} = \frac{1}{r}\mathbf{E}_t\left[V_{t+1}^b + \int_{-\bar{z}}^{-V_{t+1}^e} (z + V_{t+1}^e - \xi B_{t+1}) d\Phi(z)\right],$$

and no-Ponzi and no-bubble conditions, where $V_t^b = \{L(B_t, Q_t) + \lambda(Q_t) + [1 - \lambda(Q_t)]Q_t\}B_t$; $\lambda(.)$ and $L(.)$ are given by (12) and (13); R^t is the history of aggregate productivities up to period t.

4.1.3 Markov-perfect regulator

Given B and law of motion for R, a Markov-perfect regulator solves:

$$H(R, B) = \max_{B'} \; R + L\left(B, Q\left(R, B'\right)\right) B - \xi B \Phi\left(-V^e(R, B, B')\right) + \frac{1}{r}\mathbf{E} H(R', B'), \qquad (15)$$

given

$$
\begin{aligned}
V^e(R,B,B') &= R - \lambda(Q(R,B'))B + Q(R,B')\{B' - [1-\lambda(Q(R,B'))]B\} \\
&\quad + \frac{1}{r}\mathbf{E}\left\{\int_{-V^e(R',B',h_B(R',B'))}^{\bar{z}} [z' + V^e(R',B',h_B(R',B'))]d\Phi(z')\right\}, \qquad (16) \\
Q(R,B')B' &= \frac{1}{r}\mathbf{E}\Bigg\{V^b(B', Q(R', h_B(R',B'))) \\
&\quad + \int_{-\bar{z}}^{-V^e(R',B',h_B(R',B'))} [z' + V^e(R',B',h_B(R',B')) - \xi B']d\Phi(z')\Bigg\},
\end{aligned}
$$

where $V^b(B,Q) = \{L(B,Q) + \lambda(Q) + Q[1-\lambda(Q)]\}B$; $h_B(R,B)$ solves (15); $\lambda(.)$ and $L(.)$ are given by (12) and (13).

4.2 Solution

For the Ramsey problem, we show the existence of a pseudo steady state in some aggregate quantities. Specifically, B_t, Q_t and V_t^e converge to a stationary point. However, Lagrange multipliers associated with equity and pricing constraints, even when multiplied by r^t to adjust for time discounting, keep growing at a speed under which the no-Ponzi and no-bubble conditions are satisfied. This is different from common models, i.e. consumption-saving models, where Lagrange multipliers becomes stationary after adjusted for time discounting, and is reminiscent of characterizations in the optimal taxation literature where convergence of multipliers cannot always be established. While we prove Proposition 5 for our model with non-maturing deposits, our baseline model with fixed maturity exhibits the same property. To solve the Ramsey problem requires us to first substitute out all multipliers by hand.

Proposition 5 *The existence of a Ramsey steady state in which real variables B_t, V_t^e and Q_t stay constant does not imply constant Lagrange multipliers.*

Proof. See Appendix A.5. ■

The problems of the Markov-perfect regulator and laissez-faire banks (also the partial commitment regulators later) are nontrivial to solve. Local approximations of such equations are challenging because generalized Euler equations include derivatives of policy functions which are not determined by the system of first-order conditions (Klein, Krusell and Rios-Rull, 2008). We build on Gomes, Jermann and Schmid (2016) and Dennis (2022) for a fully local method that is scalable and can solve the steady state with essentially no approximation error. Our approach can also handle the distinction between aggregate and individual state variables. To illustrate the main idea of the approach, consider the first-order condition for a laissez-faire bank in our baseline model, i.e. Equation (8), which involves a pricing derivative given by:[10]

$$
\begin{aligned}
&\frac{\partial q(B,b')}{\partial b'}b' + q(B,b') \\
&\quad = \frac{1}{r}\Bigg\{\mu(B') + [\lambda + (1-\lambda)q(B',h_b(B',b'))][1 - \xi b'\phi(-v^e(B',b')) - \Phi(-v^e(B',b'))] \\
&\qquad\qquad - \xi\Phi(-v^e(B',b')) + (1-\lambda)b'\frac{\partial q(B',h)}{\partial h}|_{h=h_b(B',b')}\frac{\partial h_b\,(B',b')}{\partial b'}\Bigg\},
\end{aligned}
$$

where $B' = \Omega(B)$. For local solutions, policy function cannot be pinned down before solving for the steady state. Therefore, with the presence of $\frac{\partial h_b(B',b')}{\partial b'}$, the system of first-order conditions used for local solutions is short one equation. To fill the gap, we iterate over the steady state and local dynamics jointly. In particular, for conjectured linear processes for $\frac{\partial h_b(B',b')}{\partial b'}$ and $\Omega(B)$, we solve for the model's steady state and then perturb it to the second order (for instance with Dynare). The computed dynamics allow us to update our conjecture. This process is repeated until convergence.

Our parametrization is as follows. A period is a year. The average profitability of bank

[10]This is obtained by differentiating the left- and right-hand sides of (2) at the same time.

assets is $R^* = 0.02$. The default loss is $\xi = 0.2$. The withdrawal cost is $\kappa = 0.1$. We assume that ν follows an exponential distribution, i.e. $f(\nu) = a\exp(-a\nu)$, with $a = 20$. These choices follow Jermann and Xiang (2023) who aim to approximately match simulated moments of the laissez-faire economy and obvious empirical counterparts. We differ in four parameters to produce a higher default risk, without which Ramsey solutions can feature steady states with zero default and less interesting local dynamics. For the zero-mean i.i.d. shocks to profitability, we set $\phi(z) = \iota_0 - \iota_1 z^2$. By imposing $\phi(\bar{z}) = 0$ and $\Phi(\bar{z}) = 1$, we can use $\bar{z}$ to pin down ι_0 and ι_1. We set $\bar{z} = 0.26$. We set the benefit of holding deposits as $\mu(B) = 0.1245 - 0.012 \times B$. Finally, we set the discount rate to $1/r = 0.9$.

4.3 Steady states

Table 1 shows the deterministic steady states for laissez-faire, Ramsey- and Markov-perfect-regulated (MP) economies. We highlight two main findings. First, by comparing laissez-faire and two regulated economies on the left panel, one can see that with regulation the default rate is a lot lower while the amount of deposits is a lot higher. By addressing dilution, capital regulation can actually increase the steady-state amount of deposits B_{ss} that banks absorb. This is despite the fact that regulators internalize that a large amount of deposits leads to a low marginal value of holding them, i.e. $\partial\mu(B)/\partial B < 0$. In laissez-faire, banks' strong incentive to dilute ex post is punished heavily by a large credit spread at the issuance stage, making deposits very costly for banks. Capital regulation assures depositors that their money is safe to some extent and therefore facilitates borrowing. Even though steady states of regulated economies admit more deposits, default risks $\Phi(-V^e_{ss})$ are much lower. This result highlights how the borrowing constraint is endogenously tightened up by banks' dilution incentive, which is in sharp contrast to models where bank deposits are insured and capital requirements reduce equilibrium debt.[11]

Table 1: **Steady states of laissez-faire and regulated economies**

Parameters: $r = 1/0.9, \xi = 0.2, \kappa = 0.1, a = 20, \mu = 0.1245 - 0.012 \times B, R^* = 0.02, \rho_R = 0, \sigma_R = 0, \bar{z} = 0.26$. For the fixed-maturity model with $\lambda = 0.3439$, we adjust $\bar{z} = 0.121$ and $\mu = 0.098 - 0.012 \times B$ for comparability between laissez-faire economies.

	Endogenous maturity			Fixed maturity		
Moments	Laissez-faire	Ramsey	MP	Laissez-faire	Ramsey	MP
B_{ss}	0.5165	1.1269	0.8166	0.5160	0.5633	0.5622
V^e_{ss}	0.1534	0.2112	0.2207	0.0897	0.1119	0.1127
$\Phi(-V^e_{ss})$	0.1089	0.0248	0.0163	0.0457	0.0041	0.0034
λ_{ss}	0.3439	0.1213	0.0707	0.3439	0.3439	0.3439
L_{ss}	0.1195	0.1177	0.1205	0.0918	0.0912	0.0913
H_{ss}	0.7046	1.4706	1.1577	0.6266	0.7093	0.7092
$1 - B_{ss}/H_{ss}$	0.2669	0.2337	0.2946	0.1764	0.2058	0.2073

Second, by comparing between two regulated economies on the left panel, we find that regulatory commitment can lead to a larger amount of deposits and a higher default risk. Naturally, commitment implies better outcomes—for instance, the total value in steady state H_{ss} is higher in the Ramsey-regulated economy. However, we do not find bank leverage B_{ss}/H_{ss} or default risk to be lower. The Ramsey regulator's ability to commit brings a better tradeoff between liquidity benefits and default costs, who ends up issuing more deposits to create liquidity while admitting more defaults. In contrast, to issue more deposits forces the Markov-perfect regulator to bear a much larger amount of default risk and is not optimal. Interestingly, we find that the steady state leverage chosen by the Ramsey regulator can be even higher than that in laissez-faire. This highlights the importance of properly accounting for regulatory commitment before making model-based policy recommendations regarding the appropriate level of capital requirements.

[11] That the amount of deposits in the laissez-faire is smaller than in the regulated economies does not imply non-binding capital requirements. For instance, in the steady states of Markov-perfect regulated economies, both under endogenous- and fixed-maturity, we have verified that bank equity value function $V^e(R, B, B')$ is locally increasing in B' when evaluated at the point $(R, B, B') = (R^*, B_{ss}, B_{ss})$. This means that banks themselves would like to absorb more deposits than the B_{ss} chosen by a Markov-perfect regulator.

In addition to these two main results, it is worth noting that the endogeneity of deposit withdrawals can significantly amplify the value of regulatory commitment. We solve on the right panel our baseline model in Section 2 with fixed maturity and no net benefit of withdrawing. We in this case fix $\lambda = 0.3439$, and then re-adjust $\mu(B) = 0.098 - 0.012 \times B$ and $\bar{z} = 0.121$ so that laissez-faire economies with and without endogenous withdrawals have a similar amount of deposits in steady states. We find that with endogenous withdrawals, commitment can produce large differences in steady state levels of deposits B_{ss} and total value H_{ss}.[12] This is because endogenous withdrawals imply that future bank leverage will affect not only the current value of unmatured deposits as in our baseline setup, but also the amount that ends up getting matured today, i.e. how many depositors end up withdrawing. This additional channel can amplify the negative effect of inefficient leverage taking resulting from lack of commitment. In particular, withdrawals affect banks' default incentive and depositors' liquidity benefits by (15), and being able to commit to future leverage allows the Ramsey regulator to better account for these effects. Our result suggests that this can further widen the difference between Ramsey and Markov-perfect regulators regarding their optimal policies and how much value can be created.

4.4 Responses to aggregate shocks

This section shows the dynamics of regulated and laissez-faire economies in response to shocks to aggregate productivity R. This experiment is informative about the optimal setting of CCyB.

Figure 1 reports the impulse responses to a negative i.i.d. R shock at $t = 10$, which represents a recession caused by, for example, a housing crisis or a pandemic that lasts for one year. Upon the shock, bank equity values fall and therefore banks default more. By

[12] In an alternative recalibration with $\mu(B) = 0.07 - 0.012 \times B$ and $\bar{z} = 0.15$, laissez-faire economies with and without endogenous withdrawals have similar steady-state leverage ratios B_{ss}/H_{ss} and default probabilities $\Phi(-V^e_{ss})$. Our results are similar.

allowing banks to issue more deposits, both Ramsey and Markov-perfect regulators inflate the equity value and incentivize banks to default less.

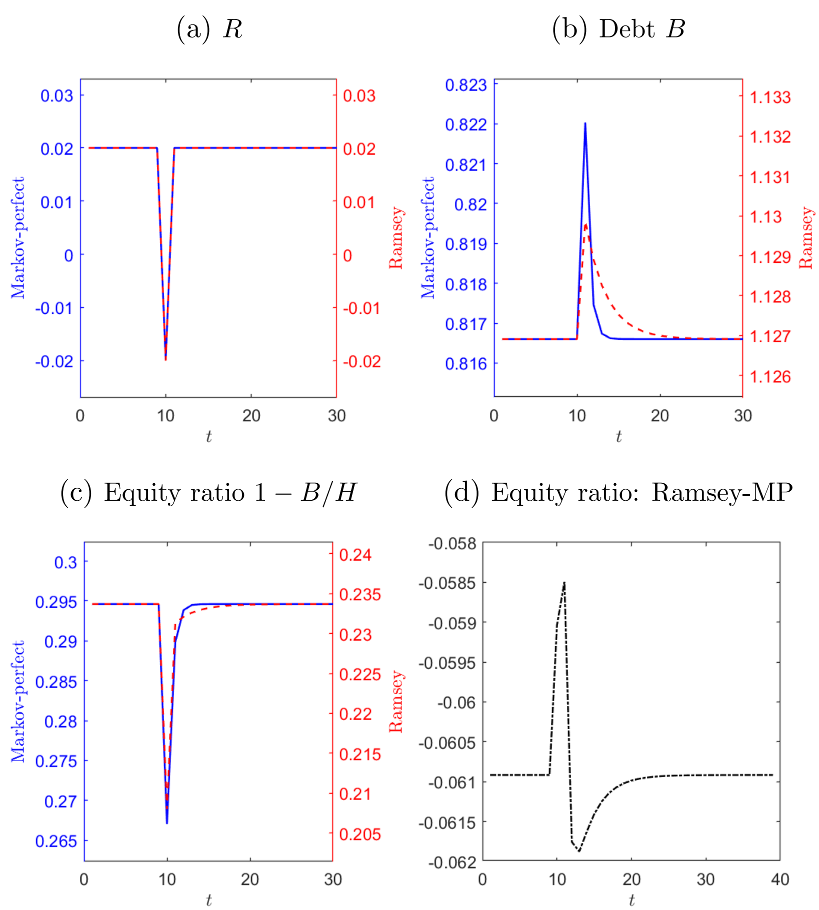

Figure 1: Regulator's commitment and impulse responses to i.i.d. R shocks. *Notes*: $\rho_R = 0, \sigma_R = 0.04$, and the other parameters follow Table 1. Ramsey-MP represents Ramsey minus Markov-perfect.

Importantly, there is a clear difference in terms of policy persistence between the two regulators. Right upon the shock, the Markov-perfect regulator aggressively increases deposits for $t = 11$. Even though an immediate deleveraging at $t = 12$ is costly because this requires banks to inject a large amount of equity to retire these deposits who are therefore very likely to default, the deleveraging still unfolds relatively rapidly. In comparison, the Ramsey regulator increases deposits for $t = 11$ in a milder way, but importantly commits to extend the increase for a longer time even though it becomes value destroying after productivity has reverted back to its long-run level. This allows Ramsey to better resolve defaults at $t = 10$. Panels (1c) and (1d) display the equity ratios $1 - B/H$ in two regulated economies and the difference between them (Ramsey-MP, i.e. Ramsey minus Markov-perfect). Relative to the Markov-perfect regulator, the Ramsey regulator keeps the equity ratio low for a longer period of time post the shock.

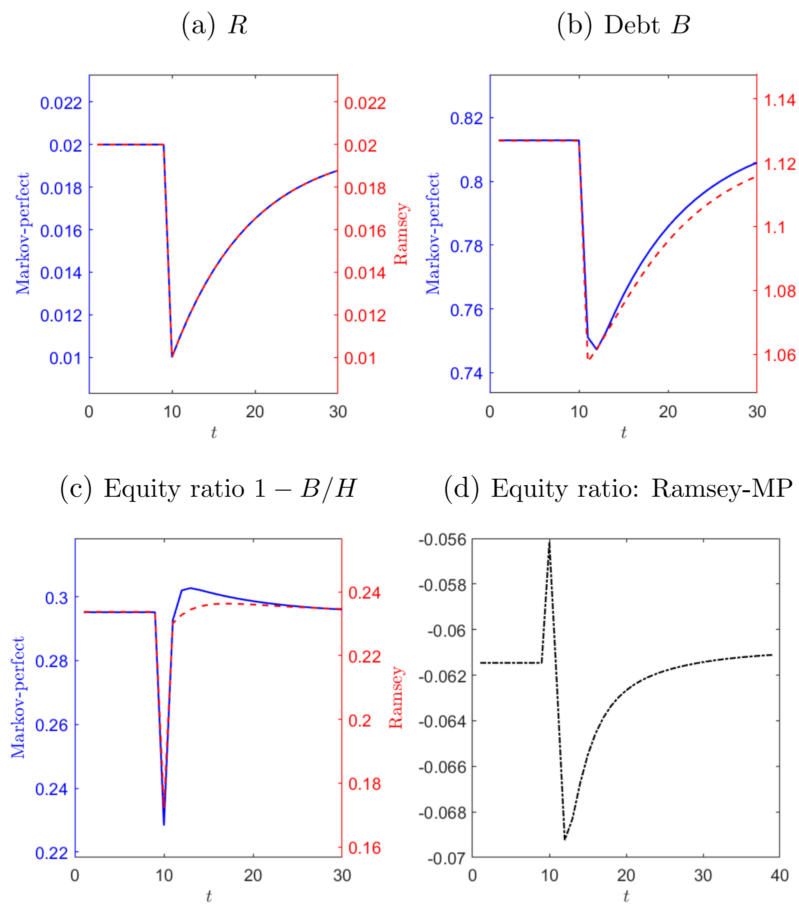

Figure 2: Regulator's commitment and impulse responses to persistent R shocks. *Notes*: $\rho_R = 0.9, \sigma_R = 0.01$, and the other parameters follow Table 1. Ramsey-MP represents Ramsey minus Markov-perfect.

Figure 2 considers a typical business cycle shock, i.e. a small but persistent drop in asset productivity R, specifically with $\rho_R = 0.9$ and $\sigma_R = 0.01$. For both regulators, aggregate bank deposits shrink drastically to reduce the exposure of banks to the long-lasting increase in default risk. By (2c) and (2d), the impact of commitment echoes that in the i.i.d. shock case—that is, relative to the Markov-perfect regulator, the Ramsey regulator adopts a low equity ratio for quite a period of time. Overall, our result lends support to policy designs that bound the ability of a regulator to quickly revert capital buffers back to a stringent level after they get reduced, with the EU CRD IV as a prominent example. See more discussions in Section 6.3.

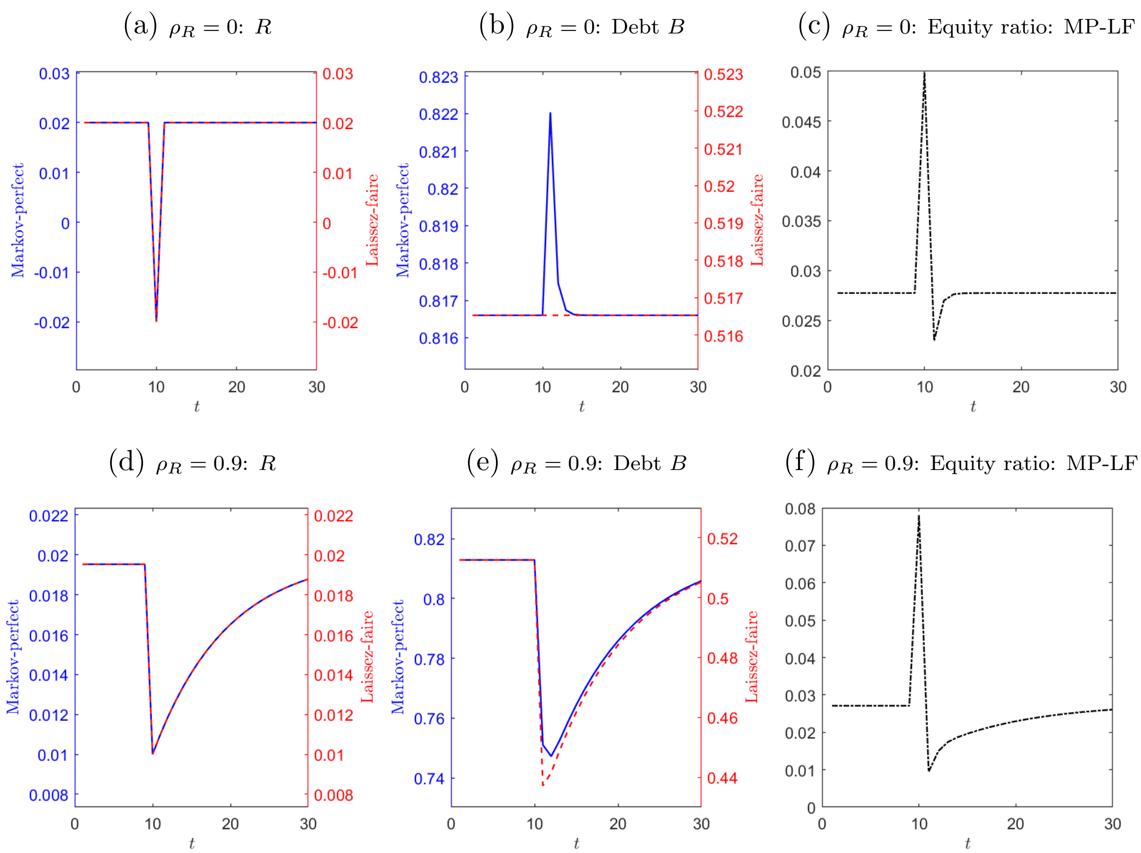

Figure 3: Laissez-faire impulse responses to R shocks. *Notes*: $\rho_R = 0, \sigma_R = 0.04$ in the upper panel and $\rho_R = 0.9, \sigma_R = 0.01$ in the lower panel. The other parameters follow Table 1. MP-LF represents Markov-perfect minus laissez-faire.

Figure 3 plots the responses of the laissez-faire economy to negative productivity shocks and compares them with those of the Markov-perfect regulated economy (MP-LF represents

Markov-perfect minus laissez-faire). Panels (3a)-(3c) show the i.i.d. shock case. When shocks are i.i.d., banks themselves do not adjust the amount of deposits, which implies that post-shock periods do not observe a lower equity ratio. This is because equity value is already maximized under banks' own choice for b', and therefore pushing it up further does not help reduce default probability. In contrast, the regulator restricts deposit issuance in steady state to address dilution, and has the room to allow more deposits to temporarily increase equity value when a negative shock hits. Panel (3c) shows that capital regulation stringency, the difference between the required capital ratio and banks' own optimal choice, falls right following the shock. Panels (3d)-(3f) show the persistent shock case. Similar to the i.i.d. case, capital regulation stringency reduces post the shock.

5 Partial commitment

Following the two polar cases, i.e. Ramsey with full commitment and Markov-perfect with no commitment, we now present two intermediate cases. The difference between Ramsey and Markov-perfect is that the former faces two auxiliary state variables—prior promises about bank equity value and deposit price—after the initial period while the latter faces none. Each of our two regulators with partial commitment has only one of the two auxiliary state variables in the continuation problem. In the first economy, the regulator commits to bank equity values only while deposit prices are set in a time-consistent way. In the second economy, the regulator commits to deposit prices only while bank equity values are set in a time-consistent way. Presumably, committing to either equity values or deposit prices would be less involved in practice than committing to both. Therefore, how these partial commitment cases are different from the Ramsey case is of interest for policy making.

A key result we find is that partial commitment regulators pick the same steady state as Ramsey despite that they have less commitment power. Here for transparency we analyze the baseline model with a fixed maturity as in Sections 2 and 3. This result holds in our extended setup with non-maturing deposits, and we delegate the analysis to Appendix B.

5.1 Setup

Aggregate productivity R is constant. The problem of a regulator committing to bank equity values can be split into a continuation problem and an initial problem. The continuation problem is given recursively:

$$H(B, V^e) = \max_{B', V^{e\prime}} R + \mu(B)B - \xi B\Phi(-V^e) + \frac{1}{r}H(B', V^{e\prime}), \tag{17}$$

subject to promise keeping to equity value V^e:

$$V^e = R - \lambda B + Q(B', V^{e\prime})[B' - (1-\lambda)B] + \frac{1}{r}\left[\int_{-V^{e\prime}}^{\bar{z}} (V^{e\prime} + z')d\Phi(z')\right], \tag{18}$$

given a deposit pricing schedule:

$$\begin{aligned} Q(B', V^{e\prime})B' = \frac{1}{r}\Big\{ & \int_{-V^{e\prime}}^{\bar{z}} V^b(B', Q(h_B(B', V^{e\prime}), h_{V^e}(B', V^{e\prime})))d\Phi(z') \\ & + \int_{-\bar{z}}^{-V^{e\prime}} [z' + V^{e\prime} + V^b(B', Q(h_B(B', V^{e\prime}), h_{V^e}(B', V^{e\prime}))) - \xi B']d\Phi(z')\Big\}, \end{aligned} \tag{19}$$

where depositors' value is $V^b(B, Q) = [\mu(B)+\lambda+(1-\lambda)Q]B$; optimal policies $B' = h_B(B, V^e)$ and $V^{e\prime} = h_{V^e}(B, V^e)$ together solve (17).

Initially, given B_0, the regulator chooses:

$$\max_{V_0^e} H(B_0, V_0^e).$$

The problem of a regulator committing to deposit prices can be formulated in a similar way. In the continuation problem, taking as given B, Q and an equity valuation schedule $V^e(B', Q'; B, Q)$, the regulator chooses deposits B' and promised deposit price Q' subject to promise keeping to deposit price Q. Initially, the regulator picks Q_0 given B_0. To save space, this problem is presented in Appendix C.

5.2 Capital regulation and partial commitment

In the two partial commitment cases, regulators have less power than Ramsey to control future deposit issuance because they can put one fewer promise keeping constraint on their future selves. Interestingly, however, we numerically solve the steady states of the three models and find them to be identical. This result implies that, in steady state, one type of commitment is sufficient to align regulators' incentives across time.

The intuition is as follows. Our result in Section 3.2 implies that for the Markov-perfect regulator, issuance decisions that maximize future total value are not consistent with maximizing current total value. To see why such a time inconsistency is absent for the partial commitment regulator, one shall first recognize the fact that total value combines equity and deposit values—total value $H = V^e + V^b(B, Q) - \xi B \Phi(-V^e)$ is increasing in both V^e and Q. In the continuation problem of a regulator committing partially to equity values, with V^e committed previously together with B, it can maximize total value only by maximizing deposit price Q. Moreover, based on the deposit pricing equation, i.e.

$$QB' = \frac{1}{r}\left[V^b(B', Q') + \int_{-\bar{z}}^{-V^{e\prime}} (z' + V^{e\prime} - \xi B') d\Phi(z')\right],$$

fixing choice variables B' and $V^{e\prime}$, decisions by the future regulator that achieve maximal Q' imply maximal Q, and there is no other forward-looking term that can potentially create a misalignment between objectives today and tomorrow. Similarly, in the continuation problem of a regulator committing partially to deposit prices, with Q committed previously together with B, it can maximize total value only by maximizing equity value V^e. Based on the equity value equation, i.e.

$$V^e = R - \lambda B + Q[B' - (1-\lambda)B] + \frac{1}{r}\left[\int_{-V^{e\prime}}^{\bar{z}} (V^{e\prime} + z')d\Phi(z')\right],$$

fixing state variables B, Q and choice variables B', decisions by the future regulator that achieve maximal $V^{e\prime}$ imply maximal V^e, and there is no other forward-looking term that can potentially create a misalignment between objectives today and tomorrow.

Formally, Proposition 6 allows the regulator with partial commitment to equity values to commit today to a small one-shot deviation in B'' away from its steady state level B_{ss} while fixing $B' = B_{ss}$. It shows that such additional commitment power does not improve total value today.[13] This is consistent with our numerical findings that steady states of this partial commitment regulator is identical to that of Ramsey, even though Ramsey has more commitment power.

Proposition 6 *In an interior steady state with $\lambda < 1$, a regulator with partial commitment to equity values cannot improve total value today by committing to a small one-shot deviation in issuance tomorrow if $\frac{\partial Q(B', V^e_{ss})}{\partial B'}|_{B'=B_{ss}} \neq -\frac{Q_{ss}[1-\Phi_{ss}+(\xi B_{ss}\phi_{ss}+\Phi_{ss})\lambda]}{B_{ss}[1-\Phi_{ss}+1-\lambda+(\xi B_{ss}\phi_{ss}+\Phi_{ss})\lambda]\lambda}$ where subscript ss denotes steady state values.*

Proof. See Appendix A.6. ■

In general, numerical solutions suggest that the allocations of the Ramsey regulator and two regulators with partial commitment are different. This is because in the initial period

[13]Once B' and B'' gets decided, promise-keeping constraints today and tomorrow pin down $V^{e\prime}$ and $V^{e\prime\prime}$. The inequality condition imposed on the steady-state pricing derivative, which can be verified numerically, rules out a knife-edge scenario where two promise keeping constraints are linearly dependent locally. Otherwise, there are multiple combinations of $\{V^{e\prime}, V^{e\prime\prime}\}$ that can satisfy promise keeping for a given choice of $\{B', B''\}$, making the one-shot deviation problem not well-identified.

there are no prior promises. Consider the regulator with partial commitment to equity values. Equity value V_0^e is not previously committed, and this means that a maximal Q_0 does not necessarily correspond to a maximal H_0. Our reasoning above no longer holds. Future regulator's decisions that achieve maximal Q_1 might not be optimal for today.

Overall, our analysis shows that while it is fairly valuable to have one type of credible promises that a regulator can make, adding a second one can encounter strongly diminishing returns in the long run. Interpreting a commitment to equity values as a commitment to bank shareholders and a commitment to deposit prices as a commitment to depositors or other debt holders of banks, our result suggests that a regulator can be very effective without cultivating close relations with both groups. For instance, a close relation to banks' shareholders or managers would be sufficient in the long run from this perspective. The ability to make credible commitments is more important than to whom such commitments are made.

6 Discussions

Two features of bank deposits give rise to both banks' dilution and regulators' time inconsistency, specifically, they are subject to default risk and are long-term in nature. Section 6.1 connects these features to existing empirical findings. Section 6.2 provides evidence suggesting that banks engage in dilution. Section 6.3 provides anecdotal evidence of time inconsistency in capital regulators' policymaking.

6.1 Modeling deposits

Our model focuses on deposits that are subject to default risk and are not continuously matured or repriced. About half of US bank deposits are uninsured according to the FDIC. While large depositors can in principle split their deposits across multiple banks to improve deposit insurance coverage, managing many accounts can be quite costly. When banks fail, haircuts to these uninsured deposits can be applied. According to Ohlrogge (Forthcoming), more than 20% of bank failures between 1992 and 2022 in the US led to losses on uninsured deposits. In some other cases, the FDIC did manage to sell the bank and ultimately bailed out uninsured deposits. However, the resolution process could take time and uninsured depositors effectively suffered a real loss. Consistent with these observations, Maechler and McDill (2006), Egan, Hortaçsu and Matvos (2017), and Martin, Puri and Ufier (Forthcoming) find that the pricing and quantity of uninsured deposits respond to changes in bank default risks.

While uninsured depositors tend to respond to increases in bank default risks, their reactions are often limited. One example is the recent Silicon Valley Bank (SVB) failure. The market value of SVB's assets had declined significantly due to the Fed's interest rate changes. However, uninsured depositors began withdrawing only when SVB started liquidating its assets and marking them to market. Depositors' limited attention, financial knowledge, transaction costs, and bank concentration all contribute to their insensitivity to changes in fundamentals, leading to less frequent withdrawals than expected. In particular, Flannery and James (1984) examine the sensitivity of bank equity values to interest rates and show that core deposits are sticky despite their short-stated maturities. Drechsler, Savov and Schnabl (2021) examine the sensitivity of deposit rates to interest rates and highlight the role of depositors' financial sophistication and bank concentration. Relatedly, Whited, Wu and Xiao (2021) estimate demands and find that deposit demands increase with the number of bank branches and employees. Interestingly, Martin, Puri and Ufier (Forthcoming) show that for a bank on the verge of failure, uninsured depositors were actively pulling their money out. However, a large amount of uninsured transactional deposits remained with the bank, particularly from customers with long-standing relationships.

6.2 Banks' deposit dilution

Long-term defaultable debt implies that shareholders would like to engage in dilution as a result of an agency conflict. A direct implication of this is that leverage dynamics become more persistent. A firm financed by short-term debt adjusts its leverage quickly in response to shocks. In contrast, a firm financed by long-term debt is reluctant to reduce its leverage when it is high due to the current incentive to dilute. Conversely, the firm finds it hard to increase leverage when it is low because lenders anticipate future incentives to dilute. Dangl and Zechner (2021) and Chaderina, Weiss and Zechner (2022) document that firms using more long-term debt are less likely to reduce their leverage when it is high. Jungherr and Schott (2022) show that the response of firm debt to output is slower for firms with more long-term debt.

We now test whether the positive relation between debt maturity and leverage persistence is also present for banks. While it is straightforward to measure the maturity of corporate bonds, deposit maturity depends on withdrawals and is difficult to measure precisely. Building on Drechsler, Savov and Schnabl (2021), we hypothesize that depositors are alert to changes in the risk of their banks (1) if they are financially sophisticated or (2) if their banks face competition in local deposit services, making it easier for depositors to move their money to competing banks. A bank facing alert depositors can dilute less freely, and depositor discipline implies a short effective deposit maturity. In particular, we start with the county-level college degree ratio and the deposit market Herfindahl-Hirschman index, and we calculate the weighted average for each bank-year across all counties where the bank operates, using deposit amounts as weights.[14] We then average the measures across the whole sample for each bank and get our estimate of depositor (un)alertness, $College_i$ and HHI_i.

[14] Our data is from Drechsler, Savov and Schnabl (2021), who compile data from the Call Reports, FDIC and the US Census. Our sample spans between 1994 and 2017.

We run the following regression:

$$Lev_{i,t} = \beta_0 Lev_{i,t-1} + \beta_1 College_i \times Lev_{i,t-1} + Controls_{i,t-1} + \Gamma_t + \varsigma_i + \epsilon_{i,t} \tag{20}$$

where $Lev_{i,t}$ is the deposit-to-asset ratios of bank i at quarter t. $College_i$ is the depositors' college degree ratio for bank i. Controls include log assets, ROA, ratio of securities to assets, and ratio of core deposits (demand deposits, saving deposits, and time deposits below $100,000) to total deposits. We also include bank and time fixed effects. We drop banks whose average deposit-to-asset ratio is at the bottom 10%, as these banks primarily rely on non-deposit financing, making depositor alertness less relevant for their debt maturity.

We are interested in β_1, which we expect to be negative. This suggests that banks with more alert depositors exhibit less persistence in their leverage, consistent with having a shorter effective maturity and being less prone to dilution problems. When replacing $College_i$ with HHI_i, we expect β_1 to be positive given it captures the unalertness of depositors. Our results presented in Table 2 are consistent with our expectations.

Lastly, it is worth noting here that if *all* deposits were insured, banks would have no incentive to dilute given there is zero "benefit". Nonetheless, when comparing across two typical banks who issue both insured and uninsured deposits, we do not expect the one with better access to insured deposits to dilute less (Jermann and Xiang, 2023). Intuitively, this is because while a bank gets a smaller "benefit" to dilute when more of its legacy deposits are insured, it incurs a smaller "cost" to dilute if it can better issue new insured deposits. In particular, banks can issue both insured and uninsured deposits to dilute the value of legacy uninsured deposits, as default decisions depend on total leverage. When issuing new uninsured deposits, banks still face some price impact, as new uninsured depositors will demand a higher credit spread due to the leverage increase. This partially constrains banks from diluting aggressively. In contrast, when issuing new insured deposits, banks do not

Table 2: **Bank dilution and depositor alertness**

Columns (1) and (2) estimate Equation (20). Column (3) and (4) estimate Equation (20) by replace $College_i$ with HHI_i. Standard errors are clustered at the bank level and reported in parentheses. ***/**/* denotes 99%/95%/90% significance.

	$Lev_{i,t}$			
	(1)	(2)	(3)	(4)
$Lev_{i,t-1} \times College_i$	-0.517***	-0.233***		
	(0.028)	(0.030)		
$College_i$	0.444***			
	(0.024)			
$Lev_{i,t-1} \times HHI_i$			0.375***	0.125***
			(0.022)	(0.022)
HHI_i			-0.324***	
			(0.019)	
$Lev_{i,t-1}$	0.938***	0.830***	0.762***	0.758***
	(0.006)	(0.007)	(0.005)	(0.005)
FEs	No	Yes	No	Yes
Controls	No	Yes	No	Yes
R^2	0.813	0.849	0.813	0.849
Obs	645,682	644,114	645,682	644,114

bear an additional price impact and can thus dilute more freely. Martin, Puri and Ufier (Forthcoming) document a case in which a bank issued a large amount of insured deposits before its failure, which is consistent with this result. Using the average core deposit ratio as a proxy for deposit insurance coverage, we do not find that banks with higher coverage exhibit less persistent leverage dynamics.

6.3 Regulator's time inconsistency

The main contribution of this paper is to show that long-term defaultable deposits imply a time inconsistency problem for capital regulators. There are a series of policy discussions and actions that reveal capital regulators' worry about the potential time inconsistency issue, as it could severely impair the working of policies. In particular, Committee on the Global Financial System (2016) advocates for a systematic framework that "*allows that sort of flexibility that is often associated with the term 'discretion' while avoiding the disadvantages of discretionary policy pointed out by Kydland and Prescott (1977)*". We consider our theory to have clearly pointed out for the first time one prominent but non-exclusive feature of banks that warrants such concerns. Here we provide some examples in regulators' setting of bank capital adequacy where time inconsistency and thus commitment are relevant.

6.3.1 CCyB

A key innovation of Basel III is to grant regulators the ability to adjust banks' capital adequacy dynamically through time-varying capital buffers, i.e. the CCyB. At of today, there is no consensus about how systematic risks shall be measured and how they shall be mapped into actual calibrations of bank capital adequacy. This leaves national regulators substantial discretion regarding when, by how much, and for how long CCyB will be adjusted.

Following the advice by Basel Committee on Banking Supervision (2010), the EU CRD IV (Article 136(7)) requires national authorities to announce "*where the buffer rate is decreased, the indicative period during which no increase in the buffer rate is expected, together with a justification for that period*". For example, the Bank of Italy explained in its 2015 Financial Stability Report that it would be unlikely to increase the CCyB in 2016, in particular, "*even were the rate of growth in lending to reach 5 percent at the end of 2016 (at the uppermost threshold of the likely results), the credit-to-GDP gap would still be such as to render macroprudential interventions unnecessary*". Following the reduction of the CCyB rate to 0% in March 2020, the Financial Policy Committee (FPC) of the Bank of England advised that "*to help ensure banks plan for the future and support the economy the FPC has confirmed that it expects to keep the rate at 0% for at least another year*".

As noted in Section 4.4, regulators without commitment tend to tighten capital requirements too quickly, which heavily discounts the effectiveness of the CCyB in mitigating the impact of a recession. Their announcements to keep the CCyB rate low for a sufficient amount of time can therefore be a valuable commitment device that supports an optimal path for CCyB. As pointed out by European Systemic Risk Board (2018) regarding the forward guidance practice in CCyB, "*predictive power of the CCyB rates implied by the buffer guides could be assessed against the authority's track record*", which helps to"*anchor market expectations*" and addresses the issue associated with "*the considerable amount of discretion*".

6.3.2 Other measures

While the CCyB component of capital requirements clearly involves a lot of discretion, governments can take other temporary measures that change the capital stringency banks face without explicitly varying capital requirements. One prominent example is how governments worldwide reacted to the 2008 financial crisis. In particular, many governments purchased bank stocks at a high price, including e.g. the US Troubled Asset Relief Program (TARP) and the UK bank rescue package, which resembled a temporary relaxation of capital requirements that benefits bank equity values. The planning of share buybacks by banks resembles a follow-up policy tightening given it is costly for them to issue equity. For instance, in exchange for the TARP money, banks had to give the US Treasury a 5% annual dividend before 2013 and 9% thereafter. Such a design was to incentivize banks to buy back shares in 5 years. The UK government also designed a long window to sell back the stocks it purchased through the bank rescue package. For instance, the UK government has self-imposed a 2026 deadline to fully privatize NatWest, formerly known as the Royal Bank of Scotland. Clearly, implementing these long-horizon buyback policies requires commitment.[15]

[15] Irish Minister for Finance, Paschal Donohoe, announced in June 2021 that the selling of the shares of Bank of Ireland was due to end no later than January 2022. However, an extended deadline, May 2022, was announced in November 2021. The new announcement also made clear the ability of the Minister to make

Another example is how governments made their own decisions regarding the pace to transit to Basel III, which imposes more stringent standards than its predecessors (Basel Committee on Banking Supervision, 2020). Relatedly, Gropp et al. (2024) provide evidence that European countries allowed their domestic banks to inflate "on paper" their level of regulatory capital to accommodate the 2011 Capital Exercise conducted by the European Banking Authority.[16] Countries have the discretion to accelerate or slow down the transition process, which affects banks significantly as equity issues are costly. Commitment power can be valuable in sustaining an optimal transition.

7 Conclusions

In this paper, we provide the first analysis of the time inconsistency problem of bank capital regulation. When financed with long-term defaultable deposits, banks in laissez-faire have an incentive to take an excessive leverage that dilutes the value of legacy depositors. Capital regulators correct the strong dilution incentive of banks but preserve some dilution as such leniency is valuable for reducing bank defaults. A regulator with commitment can use promises to future leniency—allowing an excessive leverage that implies a suboptimally high level of dilution tomorrow—to persuade banks to not default today. We show that commitment has long-run effects that are significant. Additionally, upon a negative shock, we show that regulators find a temporary relaxation of capital requirements beneficial, and one with commitment uses promises to extend such leniency into a longer period of time. Our theory echoes policy makers' preliminary attempts to develop a systematic framework that limits the discretion of capital regulators.

We have intentionally kept our model simple so that we can illustrate the time inconsis-

further extensions.

[16] Maddaloni and Scopelliti (2019) show that prior to the crisis, prudential regulation in the EU was implemented non-uniformly across countries.

tency problem of capital regulation with transparency. Even though we have incorporated non-maturing deposits to reflect a salient feature of bank debt relative to typical non-financial corporate debt, there are other features worth incorporating from a quantitative standpoint. For instance, while we have been focusing on the standard agency conflict between equity holders and depositors of a bank, i.e. a dilution problem, the model can be easily extended to allow distortions from deposit insurance. The existence of insured deposits will not change the key insights of the paper but can be valuable for making precise quantitative prescriptions. Furthermore, it is interesting to consider a full-blown general equilibrium model with firm production, capital accumulation, and household preferences. We leave these to future research.

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Appendix

A Proofs

A.1 Proposition 1

The Lagrangian for our sequential Ramsey regulator in Section 2.2.1 is:

$$\max_{\{V_t^e, Q_t, B_{t+1}, \gamma_t, \zeta_t\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \frac{1}{r^t} \Bigg\{ R + \mu(B_t)B_t - \xi B_t \Phi(-V_t^e)$$
$$+ \gamma_t \Bigg\{ R - \lambda B_t + Q_t[B_{t+1} - (1-\lambda)B_t]$$
$$+ \frac{1}{r}\left[\int_{-V_{t+1}^e}^{\bar{z}} (z + V_{t+1}^e) d\Phi(z)\right] - V_t^e \Bigg\}$$
$$+ \zeta_t \Bigg\{ \frac{1}{r}\Bigg[\left[\mu(B_{t+1}) + \lambda + (1-\lambda)Q_{t+1}\right] B_{t+1}$$
$$+ \int_{-\bar{z}}^{-V_{t+1}^e} (z + V_{t+1}^e - \xi B_{t+1}) d\Phi(z) \Bigg] - Q_t B_{t+1} \Bigg\} \Bigg\},$$

where γ_t and ζ_t are two Lagrange multipliers; B_0 is predetermined.

An interior equilibrium allocation can be solved through three sets of first-order conditions (with respect to B_{t+1}, V_t^e, Q_t) and two sets of constraints. First-order conditions at time $t > 0$ are given by:

$$\frac{1}{r}\{\mu_{t+1} + B_{t+1}\mu_{t+1}^B - \xi\Phi(-V_{t+1}^e) - \gamma_{t+1}[\lambda + Q_{t+1}(1-\lambda)]\} + \gamma_t Q_t$$
$$+ \zeta_t \left\{ \frac{1}{r}[\lambda + \mu_{t+1} + B_{t+1}\mu_{t+1}^B + (1-\lambda)Q_{t+1} - \xi\Phi(-V_t^e)] - Q_t \right\} = 0,$$

$$\gamma_t[B_{t+1} - (1-\lambda)B_t] - \zeta_t B_{t+1} + \zeta_{t-1}(1-\lambda)B_t = 0,$$

$$\xi\phi(-V_t^e)B_t - \gamma_t + \gamma_{t-1}[1 - \Phi(-V_t^e)] + \zeta_{t-1}[\Phi(-V_t^e) + \xi\phi(-V_t^e)B_t] = 0,$$

where μ^B represents the derivative of $\mu(B_t)$ with respect to B_t.

Meanwhile, first-order conditions at $t = 0$ are:

$$\frac{1}{r}\{\mu_{t+1} + B_{t+1}\mu^B_{t+1} - \xi\Phi(-V^e_{t+1}) - \gamma_{t+1}[\lambda + Q_{t+1}(1-\lambda)]\} + \gamma_t Q_t$$
$$+ \zeta_t\left\{\frac{1}{r}[\lambda + \mu_{t+1} + B_{t+1}\mu^B_{t+1} + (1-\lambda)Q_{t+1} - \xi\Phi(-V^e_t)] - Q_t\right\} = 0,$$
$$\gamma_t[B_{t+1} - (1-\lambda)B_t] - \zeta_t B_{t+1} = 0,$$
$$\xi\phi(-V^e_t)B_t - \gamma_t = 0.$$

Now consider the first-order conditions for the continuation problem in Proposition 1. They are given by:

$$\frac{1}{r}\left\{\mu' + \mu^{B\prime}B' - \xi\Phi(-V^{e\prime}) - \gamma'[\lambda + Q'(1-\lambda)]\right\} + \gamma Q$$
$$+ \zeta\left\{\frac{1}{r}\left[\lambda + \mu' + \mu^{B\prime}B' + (1-\lambda)Q' - \xi\Phi(-V^{e\prime})\right] - Q\right\} = 0,$$
$$\gamma'[B'' - (1-\lambda)B'] - \zeta' B'' + \zeta\,(1-\lambda)\,B' = 0,$$
$$\xi B'\phi(-V^{e\prime}) - \gamma' + \gamma[1 - \Phi(-V^{e\prime})] + \zeta\left[\Phi(-V^{e\prime}) + \xi B'\phi(-V^{e\prime})\right] = 0,$$

where γ and ζ are multipliers associated with promise keeping constraints on equity value and deposit price, respectively.

Two additional conditions that pin down Q_0 and V^e_0 in the initial problem are:

$$\gamma\,[B' - (1-\lambda)B] - \zeta B' = 0,$$
$$\xi\phi(-V^e)B - \gamma = 0.$$

One can see that these two sets of first-order conditions are identical. Together with identical constraints on bank equity values and deposit prices, they imply identical interior allocations.

A.2 Proposition 2

For the Ramsey regulator, plug (4) into (3) and we get $V^e + [\lambda + (1-\lambda)Q]B = R + \frac{1}{r}[V^{e\prime} + V^b(B', Q') - \xi B'\Phi(-V^{e\prime})]$. Conjecture (9) to hold, and we can then rewrite the objective into $V^e + V^b(B, Q) - \xi B\Phi(-V^e)$. We have verified our conjecture.

For the Markov-perfect regulator, plug (7) into (6) and we get $V^e(B, B') + [\lambda + (1-\lambda)Q(B')]B = R + \frac{1}{r}\left[V^e(B', h_B(B')) + V^b(B', Q(h_B(B'))) - \xi B'\Phi(-V^e(B', h_B(B')))\right]$. Conjecture (10) to hold, and we can then rewrite the objective into $V^e(B, B') + V^b(B, Q(B')) - \xi B\Phi\left(-V^e\left(B, B'\right)\right)$. At optimum $B' = h_B(B)$, and we have verified our conjecture.

A.3 Proposition 3

Define the objective of a Markov-perfect regulator in Equation (5) as $\tilde{H}(B, B') \equiv R + \mu(B)B - \xi B\Phi(-V^e(B, B')) + \frac{1}{r}H(B')$ where value and pricing functions are given by (6) and (7). Denote steady-state values under a Markov-perfect regulator with subscript ss. The first-order condition in steady state implies:

$$\frac{\partial \tilde{H}(B, B')}{\partial B'}|_{B=B'=B_{ss}} = 0.$$

Interior solution implies that deposits $B_{ss} > 0$ and default probability $\Phi_{ss} \in (0, 1)$.

We consider a regulator who chooses B' and B'' today at time t and follows the optimal policy of a Markov-perfect regulator beyond $t+2$. Our goal is to show that if conditions (i) and (ii) are satisfied, the objective of this regulator is strictly increasing in B'' when evaluated at the point where $B = B' = B'' = B_{ss}$. This makes a one-shot deviation to $B'' > B_{ss}$ profitable. This regulator's problem is given by:

$$\max_{B', B''} \; R + \mu(B)B - \xi B\Phi(-\tilde{V}^e(B, B', B'')) + \frac{1}{r}\tilde{H}(B', B'') \tag{21}$$

where

$$\tilde{V}^e(B,B',B'') = R - \lambda B + \tilde{Q}(B',B'')[B' - (1-\lambda)B] + \frac{1}{r}\left\{\int_{-V^e(B',B'')}^{\bar{z}} [z' + V^e(B',B'')]\, d\Phi(z')\right\}, \tag{22}$$

and

$$\tilde{Q}(B',B'')B' = \frac{1}{r}\Big\{[\mu(B') + \lambda + Q(B'')(1-\lambda)]B' + \int_{\bar{z}}^{-V^e(B',B'')} [z' + V^e(B',B'') - \xi B']\, d\Phi(z')\Big\}. \tag{23}$$

Combine (6) and (7), and then utilize (10). We can show:

$$V^e(B',B'') - \xi B'\Phi(-V^e(B',B'')) + V^b(B',Q(B'')) = \tilde{H}(B',B''). \tag{24}$$

where $V^b(B,Q) = [\mu(B) + \lambda + Q(1-\lambda)]B$. After plugging (23) into (22) and then using (24), we have:

$$\tilde{V}^e(B,B',B'') = R - \lambda B - (1-\lambda)B\tilde{Q}(B',B'') + \frac{1}{r}\tilde{H}(B',B'').$$

Differentiate the objective in (21) with respect to B''. Since $\frac{\partial \tilde{H}(B',B'')}{\partial B''}|_{B'=B''=B_{ss}} = 0$, the derivative at $B = B' = B'' = B_{ss}$ is given by:

$$-\xi B_{ss}\phi_{ss}(1-\lambda)B_{ss}\frac{\partial \tilde{Q}(B',B'')}{\partial B''}|_{B'=B''=B_{ss}}. \tag{25}$$

Given condition (ii), i.e. $\lambda < 1$, to show that (25) is strictly positive, it is sufficient to show that $\frac{\partial \tilde{Q}(B',B'')}{\partial B''}|_{B'=B''=B_{ss}} < 0$.

Using (24), we can rewrite (23) into:

$$\tilde{Q}\left(B', B''\right) B' = \frac{1}{r}\left\{\tilde{H}(B', B'') - \int_{-V^e(B',B'')}^{\bar{z}} \left[z' + V^e\left(B', B''\right)\right] d\Phi(z')\right\}.$$

Differentiate it with respect to B'' and then evaluate at steady state:

$$\frac{\partial \tilde{Q}(B', B'')}{\partial B''}|_{B'=B''=B_{ss}} = -\frac{1}{r}(1-\Phi_{ss})\frac{1}{B_{ss}}\frac{\partial V^e(B', B'')}{\partial B''}|_{B'=B''=B_{ss}}.$$

Here we again have utilized that $\frac{\partial \tilde{H}(B',B'')}{\partial B''}|_{B'=B''=B_{ss}} = 0$. To sign this expression, differentiate (24) with respect to B'' and then evaluate at steady state:

$$\frac{\partial V^e(B', B'')}{\partial B''}|_{B'=B''=B_{ss}}(1+\xi B_{ss}\phi_{ss}) + (1-\lambda)B_{ss}\frac{\partial Q(B'')}{\partial B''}|_{B''=B_{ss}} = \frac{\partial \tilde{H}(B', B'')}{\partial B''}|_{B'=B''=B_{ss}} = 0.$$

Condition (i), i.e. $\frac{\partial Q(B')}{\partial B'}|_{B'=B_{ss}} < 0$, and (ii), i.e. $\lambda < 1$, together imply that $\frac{\partial V^e(B',B'')}{\partial B''}|_{B'=B''=B_{ss}} > 0$. This implies $\frac{\partial \tilde{Q}(B',B'')}{\partial B''}|_{B'=B''=B_{ss}} < 0$.

A.4 Proposition 4

Denote steady state values in laissez-faire with subscript ss, which implies $B_{ss} = \Omega(B_{ss})$. Define the objective of a laissez-faire bank in Equation (1) as $\tilde{v}^e(B_{ss}, b, b') \equiv R - \lambda b + q(B_{ss}, b')[b' - (1-\lambda)b] + \frac{1}{r}\int_{-v^e(B_{ss},b')}^{\bar{z}}[z' + v^e(B_{ss}, b')]d\Phi(z')$ where pricing function is given by (2). The first-order condition in steady state implies:

$$\frac{\partial \tilde{v}^e(B_{ss}, B_{ss}, b')}{\partial b'}|_{b'=B_{ss}} = 0.$$

Interior solution implies that deposits $B_{ss} > 0$ and default probability $\Phi_{ss} \in (0, 1)$.

We consider a bank who chooses b' and b'' today at time t and follows the optimal policy of a laissez-faire bank without commitment beyond $t+2$. Our goal is to show that if conditions

(i) and (ii) are satisfied, the objective of this bank is strictly decreasing in b'' when evaluated at the point where $B = b = b' = b'' = B_{ss}$. This makes a one-shot deviation to $b'' < B_{ss}$ profitable. This bank's problem is given by:

$$\max_{b',b''} \; R - \lambda b + \tilde{q}(B_{ss}, b', b'')[b' - (1-\lambda)b] + \frac{1}{r}\left\{ \int_{-\tilde{v}^e(B_{ss},b',b'')}^{\bar{z}} [z' + \tilde{v}^e(B_{ss}, b', b'')] d\Phi(z') \right\} \tag{26}$$

where

$$\tilde{q}(B_{ss}, b', b'')b' = \frac{1}{r}\Bigg\{ [\mu(B_{ss}) + \lambda + (1-\lambda)q(B_{ss}, b'')]b' + \int_{-\bar{z}}^{-\tilde{v}^e(B_{ss},b',b'')} [z' + \tilde{v}^e(B_{ss}, b', b'') - \xi b'] d\Phi(z') \Bigg\}. \tag{27}$$

Differentiate the objective in (26) with respect to b''. Since $\frac{\partial \tilde{v}^e(B_{ss},B_{ss},b'')}{\partial b''}|_{b''=B_{ss}} = 0$, the derivative at $B = b = b' = b'' = B_{ss}$ is given by:

$$\lambda B_{ss} \frac{\partial \tilde{q}(B_{ss}, B_{ss}, b'')}{\partial b''}|_{b''=B_{ss}}. \tag{28}$$

To show that (28) is strictly negative, it is sufficient to show that $\frac{\partial \tilde{q}(B_{ss},B_{ss},b'')}{\partial b''}|_{b''=B_{ss}} < 0$.

Differentiate (27) with respect to b'' and then evaluate at steady state:

$$\frac{\partial \tilde{q}(B_{ss}, B_{ss}, b'')}{\partial b''}|_{b''=B_{ss}} = \frac{1}{r}(1-\lambda)\frac{\partial q(B_{ss}, b'')}{\partial b''}|_{b''=B_{ss}}.$$

Here we again utilize that $\frac{\partial \tilde{v}^e(B_{ss},B_{ss},b'')}{\partial b''}|_{b''=B_{ss}} = 0$. Condition (i), i.e. $\frac{\partial q(B_{ss},b')}{\partial b'}|_{b'=B_{ss}} < 0$, and (ii), i.e. $\lambda < 1$, together imply that $\frac{\partial \tilde{q}(B_{ss},B_{ss},b'')}{\partial b''}|_{b''=B_{ss}} < 0$.

A.5 Proposition 5

The Lagrangian for our sequential Ramsey regulator with non-maturing deposits is

$$\max_{\left\{\substack{V_t^e(R^t), Q_t(R^t) \\ B_{t+1}(R^t), \gamma_t(R^t), \zeta_t(R^t)}\right\}_{t=0}^{\infty}} \mathbf{E}_0 \sum_{t=0}^{\infty} \frac{1}{r^t} \Bigg\{ R_t + L(B_t, Q_t)B_t - \xi B_t \Phi(-V_t^e)$$

$$+ \gamma_t \Bigg\{ R_t - \lambda(Q_t)B_t + Q_t[B_{t+1} - (1-\lambda(Q_t))B_t]$$

$$+ \frac{1}{r}\mathbf{E}_t \Bigg[\int_{-V_{t+1}^e}^{\bar{z}} (z + V_{t+1}^e) d\Phi(z) \Bigg] - V_t^e \Bigg\}$$

$$+ \zeta_t \Bigg\{ \frac{1}{r}\mathbf{E}_t \Bigg[\left[L(B_{t+1}, Q_{t+1}) + \lambda(Q_{t+1}) + (1-\lambda(Q_{t+1}))Q_{t+1}\right] B_{t+1}$$

$$+ \int_{-\bar{z}}^{-V_{t+1}^e} (z + V_{t+1}^e - \xi B_{t+1}) d\Phi(z) \Bigg] - Q_t B_{t+1} \Bigg\} \Bigg\},$$

where $L(B_t, Q_t) = \mu(B_t) + \int_{Q_t+\kappa-1}^{\bar{\nu}} (\nu - \kappa) dF(\nu)$ and $\lambda(Q_t) = 1 - F(Q_t + \kappa - 1)$; γ_t and ζ_t are two Lagrange multipliers; R^t is the history of shocks up till time t; B_0 is predetermined.

First-order conditions in state R^t at time t are given by:

$$\frac{1}{r}\mathbf{E}_t\{L_{t+1} + B_{t+1}L_{t+1}^B - \xi\Phi(-V_{t+1}^e) - \gamma_{t+1}[\lambda_{t+1} + Q_{t+1}(1-\lambda_{t+1})]\} + \gamma_t Q_t$$
$$+ \zeta_t \left\{ \frac{1}{r}\mathbf{E}_t[\lambda_{t+1} + L_{t+1} + B_{t+1}L_{t+1}^B + (1-\lambda_{t+1})Q_{t+1} - \xi\Phi(-V_t^e)] - Q_t \right\} = 0, \tag{29}$$

$$L_t^Q B_t + \gamma_t[-\lambda_t^Q B_t + B_{t+1} - (1-\lambda_t)B_t + \lambda_t^Q Q_t B_t]$$
$$- \zeta_t B_{t+1} + \zeta_{t-1}(\lambda_t^Q + L_t^Q + 1 - \lambda_t - \lambda_t^Q Q_t)B_t = 0, \tag{30}$$

$$\xi\phi(-V_t^e)B_t - \gamma_t + \gamma_{t-1}[1 - \Phi(-V_t^e)] + \zeta_{t-1}[\Phi(-V_t^e) + \xi\phi(-V_t^e)B_t] = 0, \tag{31}$$

where L^B and L^Q represent derivatives of $L(B_t, Q_t)$ with respect to B_t and Q_t respectively; λ^Q represents the derivative of $\lambda(Q_t)$ with respect to Q_t.

Define $\gamma_t^* = \gamma_t + 1$ and $\zeta_t^* = \zeta_t + 1$. Set deposits, equity value and deposit price to their steady-state levels, i.e. B_{ss}, V^e_{ss} and Q_{ss}. Equations (29), (31) and (30) evolve into:

$$\gamma^*_{t+1} = A^0\gamma^*_t + A^1\zeta^*_t, \tag{32}$$

$$\gamma^*_t = B^0\gamma^*_{t-1} + B^1\zeta^*_{t-1}, \tag{33}$$

$$\zeta^*_t = \Omega_{ss}B^0\gamma^*_{t-1} + [\Omega_{ss}B^1 + (1 + L^Q_{ss} - \Omega_{ss})]\zeta^*_{t-1}, \tag{34}$$

where $\Omega_{ss} = \lambda_{ss} + (Q_{ss} - 1)\lambda^Q_{ss}$ and

$$\begin{aligned}
A^0 &= \frac{rQ_{ss}}{\lambda_{ss} + (1-\lambda_{ss})Q_{ss}}, \\
A^1 &= \frac{\lambda_{ss} + L_{ss} + B_{ss}L^B_{ss} + (1-\lambda_{ss})Q_{ss} - \xi\Phi(-V^e_{ss}) - rQ_{ss}}{\lambda_{ss} + (1-\lambda_{ss})Q_{ss}}, \\
B^0 &= 1 - \Phi(-V^e_{ss}), \\
B^1 &= \Phi(-V^e_{ss}) + \xi\phi(-V^e_{ss})B_{ss}.
\end{aligned}$$

Some manipulations yield:

$$\zeta^*_t = \left\{[\Omega_{ss}B^1 + (1 + L^Q_{ss} - \Omega_{ss})] - \Omega_{ss}B^0\frac{A^1 - B^1}{A^0 - B^0}\right\}\zeta^*_{t-1}.$$

We know that $(A^0 - B^0)\gamma^*_t + (A^1 - B^1)\zeta^*_t = 0$, which means that

$$\left\{[\Omega_{ss}B^1 + (1 + L^Q_{ss} - \Omega_{ss})] - \Omega_{ss}B^0\frac{A^1 - B^1}{A^0 - B^0} + A^1\frac{A^0 - B^0}{A^1 - B^1} - A^0\right\}\zeta^*_{t-1} = 0.$$

Setting the term in the bracket to zero gives us the condition we need in addition to two constraints to solve for B_{ss}, Q_{ss} and V^e_{ss}. We verify numerically that under our calibration there exists a $\{B_{ss}, Q_{ss}, V^e_{ss}\}$ that solves these three equations. However, $1 < [\Omega_{ss}B^1 + (1 + L^Q_{ss} - \Omega_{ss})] - \Omega_{ss}B^0\frac{A^1-B^1}{A^0-B^0} < r$. This serves a counter-example against constant Lagrange multipliers.

A.6 Proposition 6

First, similar to Proposition 2, it is easy to conjecture and verify that for a capital regulator with partial commitment to equity values, total value in the continuation problem is

$$H(B, V^e) = V^e + V^b(B, Q(h_B(B, V^e), h_{V^e}(B, V^e))) - \xi B\Phi(-V^e) \tag{35}$$

with $h_B(B, V^e)$ and $h_{V^e}(B, V^e)$ being its policy functions.

Plug (19) into (18) and then use (35). We can rewrite the objective of the regulator with partial commitment to equity values into:

$$R + \mu(B)B - \xi B\Phi(-V^e) + \frac{1}{r}H(B', V^{e\prime}) = V^e - \xi B\Phi(-V^e) + V^b(B, Q(B', V^{e\prime}))B.$$

Rewrite the problem of a regulator with partial commitment to equity values into

$$H(B, V^e) = \max_{B'} V^e - \xi B\Phi(-V^e) + V^b(B, Q(B', U(B', B, V^e)))B \tag{36}$$

where $U(B', B, V^e)$ is given implicitly by:

$$\begin{aligned} V^e = R - \lambda B + Q(B', U(B', B, V^e))[B' - (1-\lambda)B] \\ + \frac{1}{r}\left\{\int_{-U(B',B,V^e)}^{\bar{z}} [U(B', B, V^e) + z']d\Phi(z')\right\}, \end{aligned} \tag{37}$$

given pricing schedule

$$Q(B', V^{e\prime})B' = \frac{1}{r}\left\{V^b(B', Q\,(')) + \int_{-\bar{z}}^{-V^{e\prime}} [z' + V^{e\prime} - \xi B']d\Phi(z')\right\}. \tag{38}$$

with $Q\,(') \equiv Q\left(h_B\left(B', V^{e\prime}\right), U\left(h_B\left(B', V^{e\prime}\right), B', V^{e\prime}\right)\right)$ and $h_B(.)$ solving (36). In this case, given the pricing schedule, $U(B', B, V^e)$ denotes the choice for $V^{e\prime}$ that can satisfy prior promise V^e given the choice for B' and policy of the future regulator.

Denote steady state values under the partial commitment regulator with subscript ss. We know from first-order condition that

$$\partial Q_{ss}^B + \partial Q_{ss}^V \partial U_{ss} = 0.$$

where we define $\partial Q^B \equiv \frac{\partial Q(B',V^{e\prime})}{\partial B'}$, $\partial Q^V \equiv \frac{\partial Q(B',V^{e\prime})}{\partial V^{e\prime}}$, and $\partial U \equiv \frac{\partial U(B',B,V^e)}{\partial B'}$. By differentiating (37), we have

$$\lambda B_{ss} \partial Q_{ss}^B + Q_{ss} + \left[\lambda B_{ss} \partial Q_{ss}^V + \frac{1}{r}\left(1 - \Phi_{ss}\right)\right] \partial U_{ss} = 0.$$

Substitute out ∂U_{ss} and we have in steady state:

$$\partial Q_{ss}^B - \partial Q_{ss}^V \frac{\lambda B_{ss} \partial Q_{ss}^B + Q_{ss}}{\lambda B_{ss} \partial Q_{ss}^V + \frac{1}{r}\left(1 - \Phi_{ss}\right)} = 0. \tag{39}$$

We consider a regulator who chooses B' and B'' today at time t and follows the optimal policy of a partial commitment regulator beyond $t+2$. Our goal is to show the condition under which the derivative of its objective with respect to B'' is 0 when evaluated at the point implied by (39).

This regulator's problem is given by:

$$\begin{aligned} \max_{B',B''} \; & R + \mu(B)B - \xi B \Phi\left(-V^e\right) \\ & + \frac{1}{r}\left\{R + \mu(B')B' - \xi B' \Phi(-\tilde{U}\left(B', B'', B, V^e\right))\right\} + \frac{1}{r^2} H(B'', \hat{U}(B', B'', B, V^e)), \end{aligned} \tag{40}$$

where today's promise $\tilde{U}(B', B'', B, V^e)$ is given by

$$V^e = R - \lambda B + \tilde{Q}(B', B'', B, V^e)[B' - (1-\lambda)B] + \frac{1}{r}\left\{\int_{-\tilde{U}(B',B'',B,V^e)}^{\bar{z}} [\tilde{U}(B', B'', B, V^e) + z'] d\Phi(z')\right\} \quad (41)$$

and tomorrow's promise $\hat{U}(B', B'', B, V^e) \equiv U(B'', B', \tilde{U}(B', B'', B, V^e))$ is given by

$$\tilde{U}(B', B'', B, V^e) = R - \lambda B' + Q(B'', \hat{U}(B', B'', B, V^e))[B'' - (1-\lambda)B'] + \frac{1}{r}\left\{\int_{-\hat{U}(B',B'',B,V^e)}^{\bar{z}} [\hat{U}(B', B'', B, V^e) + z'] d\Phi(z')\right\}, \quad (42)$$

given

$$\tilde{Q}(B', B'', B, V^e)B' = \frac{1}{r}\Bigg\{V^b(B', Q(B'', \hat{U}(B', B'', B, V^e))) + \int_{-\bar{z}}^{-\tilde{U}(B',B'',B,V^e)} [z' + \tilde{U}\,(B', B'', B, V^e) - \xi B'] d\Phi(z')\Bigg\}. \quad (43)$$

Plug (43) into (41):

$$\begin{aligned} &V^e - \xi B \Phi\,(-V^e) + V^b(B, \tilde{Q}(B', B'', B, V^e)) \\ &= R - \xi B \Phi\,(-V^e) + \mu(B)B \\ &+ \frac{1}{r}\left[V^b(B', Q(B'', \hat{U}(B', B'', B, V^e))) + \tilde{U}\,(B', B'', B, V^e) - \xi B' \Phi(-\tilde{U}\,(B', B'', B, V^e))\right]. \end{aligned}$$

Manipulate (42) using (38) and (35):

$$\begin{aligned} &\tilde{U}(B', B'', B, V^e) + V^b(B', Q(B'', \hat{U}(B', B'', B, V^e))) - \xi B' \Phi(-\tilde{U}\,(B', B'', B, V^e)) \\ &= R + L(B')B' - \xi B' \Phi(-\tilde{U}\,(B', B'', B, V^e)) + \frac{1}{r} H(B'', \hat{U}(B', B'', B, V^e)). \end{aligned}$$

Based on the above two equations, we can rewrite the objective of this regulator with a one-shot deviation opportunity as:

$$\max_{B',B''} V^e - \xi B\Phi(-V^e) + V^b(B, \tilde{Q}(B', B'', B, V^e)). \tag{44}$$

Now we are ready to show the condition under which the derivative of (44) with respect to B'' is 0 when evaluated at the point implied by (39), that is,

$$(1-\lambda)B_{ss}\frac{\partial \tilde{Q}(B', B'', B, V^e)}{\partial B''}_{ss} = 0. \tag{45}$$

Differentiate (41), (42), and (43) with respect to B''. We end up with three equations that allow us to solve for $\frac{\partial \tilde{Q}(B',B'',B,V^e)}{\partial B''}_{ss}$, $\frac{\partial \tilde{U}(B',B'',B,V^e)}{\partial B''}_{ss}$, and $\frac{\partial \hat{U}(B',B'',B,V^e)}{\partial B''}_{ss}$. Tedious algebra yield:

$$\begin{aligned}
&\frac{\partial \tilde{Q}(B', B'', B, V^e)}{\partial B''}_{ss}\left[1 + \frac{1-\lambda}{1-\Phi_{ss}}\frac{\frac{\lambda}{1-\Phi_{ss}}B_{ss}\partial Q^V_{ss}}{\frac{\lambda}{1-\Phi_{ss}}B_{ss}\partial Q^V_{ss} + \frac{1}{r}} + (\xi B_{ss}\phi_{ss} + \Phi_{ss})\frac{\lambda}{1-\Phi_{ss}}\right] \\
&\quad = \frac{1}{r}(1-\lambda)\left[\partial Q^B_{ss} - \partial Q^V_{ss}\frac{\lambda B_{ss}\partial Q^B_{ss} + Q_{ss}}{\lambda B_{ss}\partial Q^V_{ss} + \frac{1}{r}(1-\Phi_{ss})}\right],
\end{aligned} \tag{46}$$

of which the right-hand side is 0 by (39). It is easy to verify using (39) that if

$$\partial Q^B_{ss} \neq -\frac{Q_{ss}[1-\Phi_{ss} + (\xi B_{ss}\phi_{ss} + \Phi_{ss})\lambda]}{B_{ss}\left[1-\Phi_{ss} + 1 - \lambda + (\xi B_{ss}\phi_{ss} + \Phi_{ss})\lambda\right]\lambda},$$

the second term on the left-hand side of (46) is not 0. This implies that $\frac{\partial \tilde{Q}(B',B'',B,V^e)}{\partial B''}_{ss} = 0$.

B One-shot commitments with non-maturing deposits

It is straightforward to show that Propositions 1 and 2 carry through into our extended model with non-maturing deposits. First, the sequential problem of a Ramsey regulator can be reformulated into a continuation problem and an initial problem, with the former being recursive. In the case with shocks, promised equity values and deposit prices in the continuation problem are contingent on states next period R', that is, given current state $\{R, B, V^e, Q\}$, a Ramsey regulator chooses $\{B', V^{e\prime}(R'), Q'(R')\}$; in the initial problem the regulator picks a pair of $\{V_0^e, Q_0\}$ for each R_0. Second, the regulators' objective $H = V^e + V^b(B,Q) - \xi B\Phi(-V^e)$ where $V^b(B,Q) = \{L(B,Q) + \lambda(Q) + [1-\lambda(Q)]Q\}B$ with $\lambda(.)$ and $L(.)$ given by (12) and (13). While we do not provide a detailed proof here to save space, they are available upon request.

B.1 Regulator's time inconsistency problem

We now show the value of commitment via a one-shot deviation exercise similar to Section 3. Proposition 7 generalizes Proposition 3 into this extended setup. In particular, a Markov-perfect regulator can improve total value today by deviating in one shot to a higher deposit issuance tomorrow when deposit maturity is long enough, if granted with such an ability to commit. In the fixed-maturity case, by committing to a higher deposit issuance tomorrow, risk-adjusted payments to legacy deposits decline and equity value today increases. With endogenous maturity, as expected payments to unwithdrawn deposits decline, more depositors will end up withdrawing today. This additional channel of withdrawals can either amplify or dampen the increase in equity value depending on whether deposits are valued above or below par—the former case implies a rollover gain and the latter a rollover loss. Overall, equity value today improves as long as the former channel is dominant—that is, when the equilibrium mass of non-withdrawing depositors $1-\lambda_{ss}$ is large.

Proposition 7 *In an interior steady state with non-maturing deposits, a Markov-perfect regulator improves total value today by committing to a small one-shot deviation to a larger issuance tomorrow if (i) deposit pricing function* $Q(.)$ *decreases in* B' *at* $B' = B_{ss}$ *and (ii)* *deposit maturity* $\lambda_{ss} < \min\{1 + \frac{1+\xi B_{ss}\phi_{ss}}{\xi B_{ss}\phi_{ss}}(Q_{ss}-1) f_{ss}, 1\}$ *where subscript* ss *denotes steady state values.*

Proof. The proof follows the same structure as Appendix A.3, and to save space, we here highlight only the differences. Fix productivity R to be constant so that it is no longer an argument of any functions. We consider a regulator who chooses B' and B'' today at time t and follows the optimal policy of a Markov-perfect regulator beyond $t+2$. The first-order condition with respect to B'' (generalizing (25)) is:

$$\{\xi B_{ss}\phi_{ss}\left[f_{ss}(1-Q_{ss}) - (1-\lambda_{ss})\right] + f_{ss}(1-Q_{ss})\} B_{ss}\frac{\partial \tilde{Q}(B',B'')}{\partial B''}|_{B'=B''=B_{ss}}, \tag{47}$$

where subscript ss denotes steady state values; $\tilde{Q}(B',B'')$ is the deposit price at time t given the choice $\{B',B''\}$.

Condition (ii), i.e. $\lambda_{ss} < 1 + \frac{1+\xi B_{ss}\phi_{ss}}{\xi B_{ss}\phi_{ss}}(Q_{ss}-1) f_{ss}$, guarantees that the first term of (47) is negative. Conditions (i) and (ii), i.e. $\lambda_{ss} < 1$, together imply that $\frac{\partial \tilde{Q}(B',B'')}{\partial B''}|_{B'=B''=B_{ss}} < 0$.

■

Proposition 8 generalizes Proposition 4 into this extended setup. In particular, a bank in laissez-faire has an incentive to deviate to a low deposit issuance tomorrow when deposit maturity is long, if granted with such an ability to commit. This commitment increases the price at which new deposits can be issued today and in turn benefits equity value. With endogenous maturity, fewer depositors will end up withdrawing expecting a smaller default risk tomorrow. Overall, equity value improves as long as new issuance λ_{ss} every period is nontrivial.

Proposition 8 *In an interior steady state with non-maturing deposits, a laissez-faire bank improves equity value today by committing to a small one-shot deviation to a lower issuance* *tomorrow if (i) deposit pricing function* $q(.)$ *decreases in* b' *at* $b' = B_{ss}$ *and (ii) deposit maturity* $\lambda_{ss} < 1$ *and* $\lambda_{ss} > (q_{ss} - 1)f_{ss}$ *where subscript ss denotes steady state values.*

Proof. The proof follows the same structure as Appendix A.4, and to save space, we here highlight only the differences. Fix productivity R to be constant so that it is no longer an argument of any functions. We consider a bank who chooses b' and b'' today at time t and follows the optimal policy of a laissez-faire bank without commitment beyond $t + 2$. The first-order condition with respect to b'' (generalizing (28)) is:

$$[\lambda_{ss} - (q_{ss} - 1)f_{ss}]\, B_{ss} \frac{\partial \tilde{q}(B_{ss}, B_{ss}, b'')}{\partial b''}|_{b''=B_{ss}}, \tag{48}$$

where subscript ss denotes steady state values; $\tilde{q}(B_{ss}, b', b'')$ is the deposit price at time t given the choice $\{b', b''\}$ and aggregate B_{ss}.

Condition (ii), i.e. $\lambda_{ss} > (q_{ss} - 1)f_{ss}$, guarantees that the first term of (48) is positive. Conditions (i) and (ii), i.e. $\lambda_{ss} < 1$, together imply that $\frac{\partial \tilde{q}(B_{ss}, B_{ss}, b'')}{\partial b''}|_{b''=B_{ss}} < 0$.

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B.2 Partial commitment

Now we present the problem of a regulator with partial commitment to equity values in our extended model with non-maturing deposits. We then show that there is no profitable one-shot deviation in steady state, again echoing our baseline results in Section 5.2. Numerically we solve the model and confirm that the steady states of two regulators with partial commitment are identical to that of Ramsey.

As we mentioned earlier, with shocks, promised values in the continuation problem of a recursively-formulated Ramsey regulator are state-contingent. The problem of a regulator committing to equity values can also be split into a continuation problem and an initial problem. The continuation problem is given recursively:

$$H(R,B,V^e) = \max_{B',V^{e\prime}(R')} R + L(B,Q(B',V^{e\prime}(R');R))B - \xi B\Phi(-V^e) + \frac{1}{r}\mathbf{E}H(R',B',V^{e\prime}(R')), \tag{49}$$

subject to promise keeping to equity value V^e:

$$\begin{aligned} V^e &= R - \lambda(Q(B',V^{e\prime}(R');R))B \\ &+ Q(B',V^{e\prime}(R');R)\{B' - [1-\lambda(Q(B',V^{e\prime}(R');R))]B\} + \frac{1}{r}\mathbf{E}\left\{\int_{-V^{e\prime}(R')}^{\bar{z}} [V^{e\prime}(R') + z']d\Phi(z')\right\}, \end{aligned}$$

given a deposit pricing schedule:

$$\begin{aligned} Q(B',V^{e\prime}(R');R)B' = \frac{1}{r}\mathbf{E}\Bigg\{ & V^b(B',Q(h_B(R',B',V^{e\prime}(R')),h_{V^e}(R'';R',B',V^{e\prime}(R'));R')) \\ & + \int_{-\bar{z}}^{-V^{e\prime}(R')} [z' + V^{e\prime}(R') - \xi B']d\Phi(z')\Bigg\}, \end{aligned}$$

where $V^b(B,Q) = \{\lambda(Q) + L(B,Q) + [1-\lambda(Q)]Q\}B$; $\lambda(.)$ and $L(.)$ are given by (12) and (13); $h_B(R,B,V^e)$ and $h_{V^e}(R';R,B,V^e)$ together solve (49).

Initially, given B_0 and R_0, the regulator chooses:

$$\max_{V_0^e} H(R_0,B_0,V_0^e).$$

Proposition 9 generalizes Proposition 6 into this extended setup. In particular, the partial-commitment regulator in steady state, if granted with the ability to commit in one shot to deposit issuance tomorrow, has no incentive to deviate. The intuition is similar to that for Proposition 6. In short, one type of commitment is sufficient to align regulator's incentives across time in the continuation problem.

Proposition 9 *In an interior steady state with non-maturing deposits where $\lambda_{ss} < 1$, a regulator with partial commitment to equity values cannot improve total value today by committing to a small one-shot deviation in issuance tomorrow if the derivative of deposit pricing function $Q(.)$ with respect to B' at $\{B' = B_{ss}, V^{e\prime} = V^e_{ss}\}$ does not equal $-\frac{Q_{ss}\{1-\Phi_{ss}+(\xi B_{ss}\phi_{ss}+\Phi_{ss})[f_{ss}(1-Q_{ss})+\lambda_{ss}]\}}{B_{ss}\{1-\Phi_{ss}+1-\lambda_{ss}+(\xi B_{ss}\phi_{ss}+\Phi_{ss})[f_{ss}(1-Q_{ss})+\lambda_{ss}]\}[f_{ss}(1-Q_{ss})+\lambda_{ss}]}$ where subscript ss denotes steady state values.*

Proof. The proof follows the same structure as Appendix A.6, and to save space, we here highlight only the differences. Fix productivity R to be constant so that it is no longer an argument of any functions.

The first-order condition for the partial-commitment regulator (generalizing (39)) implies:

$$\partial Q^B_{ss} - \partial Q^V_{ss} \frac{[f_{ss}(1-Q_{ss}) + \lambda_{ss}]\, B_{ss}\partial Q^B_{ss} + Q_{ss}}{[f_{ss}(1-Q_{ss}) + \lambda_{ss}]\, B_{ss}\partial Q^V_{ss} + \frac{1}{r}(1-\Phi_{ss})} = 0. \tag{50}$$

where subscript ss denotes steady state values; $\partial Q^B \equiv \frac{\partial Q(B', V^{e\prime})}{\partial B'}$ and $\partial Q^V \equiv \frac{\partial Q(B', V^{e\prime})}{\partial V^{e\prime}}$.

We consider a regulator who chooses B' and B'' today at time t and follows the optimal policy of a partial commitment regulator beyond $t+2$. We would like to show the condition under which the first-order derivative of its objective with respect to B'' is 0 when evaluated at the point implied by (50), that is (generalizing (45)),

$$(1-\lambda_{ss}) B_{ss} \frac{\partial \tilde{Q}(B', B'', B, V^e)}{\partial B''}\bigg|_{ss} = 0,$$

where $\tilde{Q}(B', B'', B, V^e)$ is the deposit price at time t given the choice $\{B', B''\}$ and state variables B and V^e. Differentiating two promise keeping constraints and deposit pricing function, we get (generalizing (46)):

$$\left.\frac{\partial \tilde{Q}(B', B'', B, V^e)}{\partial B''}\right|_{ss} \times \left[1 + \frac{1-\lambda_{ss}}{1-\Phi_{ss}} \frac{\frac{f_{ss}(1-Q_{ss})+\lambda_{ss}}{1-\Phi_{ss}} B_{ss} \partial Q^V_{ss}}{\frac{f_{ss}(1-Q_{ss})+\lambda_{ss}}{1-\Phi_{ss}} B_{ss} \partial Q^V_{ss} + \frac{1}{r}} + (\xi B_{ss}\phi_{ss} + \Phi_{ss}) \frac{f_{ss}(1-Q_{ss})+\lambda_{ss}}{1-\Phi_{ss}}\right] = \frac{1}{r}(1-\lambda_{ss}) \left\{\partial Q^B_{ss} - \partial Q^V_{ss} \frac{[f_{ss}(1-Q_{ss})+\lambda_{ss}] B_{ss} \partial Q^B_{ss} + Q_{ss}}{[f_{ss}(1-Q_{ss})+\lambda_{ss}] B_{ss} \partial Q^V_{ss} + \frac{1}{r}(1-\Phi_{ss})}\right\}. \tag{51}$$

The right-hand side of (51) is 0 by (50). It is easy to verify using (50) that if

$$\partial Q^B_{ss} \neq -\frac{Q_{ss}\{1-\Phi_{ss} + (\xi B_{ss}\phi_{ss} + \Phi_{ss})[f_{ss}(1-Q_{ss})+\lambda_{ss}]\}}{B_{ss}\{1-\Phi_{ss} + 1 - \lambda_{ss} + (\xi B_{ss}\phi_{ss} + \Phi_{ss})[f_{ss}(1-Q_{ss})+\lambda_{ss}]\}[f_{ss}(1-Q_{ss})+\lambda_{ss}]},$$

the second term on the left-hand side of (51) is not 0. This implies that $\left.\frac{\partial \tilde{Q}(B',B'',B,V^e)}{\partial B''}\right|_{ss} = 0$.

■

C Partial commitment to deposit prices

The problem of the regulator with partial commitment to deposit prices can be split into a continuation problem and an initial problem. The continuation problem is given by:

$$H(B,Q) = \max_{B',Q'} R + \mu(B)B - \xi B\Phi(-V^e(B',Q';B,Q)) + \frac{1}{r}H(B',Q'), \tag{52}$$

subject to a promise keeping constraint on deposit price:

$$QB' = \frac{1}{r}\left\{\int_{-V^e(')}^{\bar{z}} V^b(B',Q')d\Phi(z') + \int_{-\bar{z}}^{-V^e(')} [z' + V^e(') + V^b(B',Q') - \xi B']d\Phi(z')\right\},$$

given an equity value schedule:

$$V^e(B', Q'; B, Q) = R - \lambda B + Q[B' - (1-\lambda)B] + \frac{1}{r}\left\{\int_{-V^e(')}^{\bar{z}} [V^e(') + z'] d\Phi(z')\right\},$$

where $V^e(') \equiv V^e(h_B(B', Q'), h_Q(B', Q'); B', Q')$ with $h_B(B, Q)$ and $h_Q(B, Q)$ being optimal policies for deposits B' and promised deposit price Q' from (52); depositors' value is $V^b(B, Q) = [\mu(B) + \lambda + (1-\lambda)Q]B$.

Initially, given B_0, the regulator chooses:

$$\max_{Q_0} H(B_0, Q_0).$$