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JEL Classification: E0, E5, G01

Keywords: information-based bank runs, Pecuniary externalities, Ramsey plan, Basel regimes, equity requirements, liquidity requirements

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Insolvency-Illiquidity, Macro Externalities and Regulation*

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This draft: September 2019.

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1 Introduction

The scope and the extent of the macro-prudential regulation is a growing and pivotal area of research. So far the literature provided ground for macro-prudential regulation based on demand externalities and pecuniary externalities emerging from borrowers' constraints (see literature review in next sub-section). A primordial reason for prudential regulation is to prevent aggregate costs of bank runs and panics. Using a macro model with information-based runs, this paper shows that, even when runs are privately efficient, as they discipline delegated monitoring, the emergence of technological inefficiencies and pecuniary externalities justifies regulation, in the form of capital and liquidity requirements, and prescribes their cyclicality. In my model the interplay between the run constraint on banks and the aggregate pricing of assets predicates the emergence of macro externalities. Second, even though some form of regulation is desirable, the need for multiple ones might be questionable. As new regulations, such as liquidity requirements, are introduced, their benefits realize to the extent that they complement and do not overlap with previous ones, such as equity requirements. A major peculiarity of banking is the emergence of both illiquidity-solvency and insolvency events, each justifying a distinct role for separate regulations. Third, the efficacy and performance of new regulation largely hinges on the counteracting effects of anticipatory behaviour. Rational banks might re-balance their portfolios to side step the hook of regulation. Past literature examining regulation within static banking models, cannot delve into the unintended consequences of policy when agents' expectations react to announcements. This paper shows that the credibility of the announcement, and its distance to implementation, can inadvertently impair the power of regulation.

I examine the above issues, and more generally the optimal design of prudential regulation, using a dynamic general equilibrium model with information-based bank runs. In the model households hold banks' short-term liabilities, or demand deposits[1], and bankers choose equity capital to maximize future value functions conditional on the risk of bank runs. Bankers' optimal supply of

[1] Those are fixed claims with a sequential service constraint and include all the platform of bank short-term debt.

bank equity gives raise to an intermediary asset pricing equation, which falls with the probability of bank runs. Since both outside financiers, depositors and bank capitalists, have limited re-deploying abilities, they delegate this activity to a bank manager with such an ability. Runs emerge since banks' assets are subject to idiosyncratic shocks, upon which depositors receive precise signals, and since the sequential service constraint creates a collective action problem among depositors. Upon a bargaining agreement with the coalition of outside financiers[2], bank managers choose the leverage ratio to maximize their total expected discounted surplus and receive a compensation proportional to their bargaining power. The privately optimal leverage ratio trades-off the run risk, and its cost for the individual bank, against the higher cost of equity capital.

To see whether the model is well suited for policy analysis I first verify that it generates empirically plausible transmission mechanisms. In response to a fall in interest rates or to positive productivity shocks, bank managers increase leverage, as short-term liabilities become cheaper than equity capital and this loosens the run constraint. Such a transmission fits well the leverage pro-cyclicality typically observed before crisis[3], which in turn endogenously increases the ex post probability of a run, hence of a banking crisis. Simulations of the model show that it can also match well several moments of key macro and banking variables.

The design of optimal regulation proceeds as follows. First, to highlight the source of externalities, the efficient planner allocation and the Ramsey allocation are compared to the competitive economy. The comparison between the competitive economy and the efficient allocation highlights the role of technological externalities. In the efficient allocation the planner chooses all variables, including bank capital, to maximize the welfare of depositors and bank capitalists subject to the technological constraints. The latter comprise the technological cost of the planner to re-deploy projects. The competitive equilibrium deviates from the efficient one to the extent that bank managers' bargaining power, hence their rents' extraction, is higher than the resource cost of re-

[2]In the the negotiations with the intermediary investors's outside option consists in seizing the asset themselves. See Diamond and Rajan[11].

[3]See Hanson, Kashyap and Stein[27] or Gorton and Metrick[23] among others.

deploying projects incurred by the planner.

The role of pecuniary externalities emerges by comparing the competitive economy to a Ramsey plan. The Ramsey planner chooses the optimal allocation by maximizing welfare subject to the decentralized equilibrium conditions, which include equilibrium market prices, and implements the optimal allocation through a policy instrument, which consists in a regulatory capital requirement. In the event of a run bank managers only internalize their own bank cost of early project liquidation. However they fail to internalize that aggregate liquidation costs induce a fall in investment, which in turn triggers a fall in the price of capital. Pecuniary externalities emerge due to the constraint on short-term funding imposed by the run condition. In the event of a run higher equity capital is needed to cover losses. This raises the price of equity capital inducing a wedge between the marginal utility of depositors and bank capitalists. The higher cost of equity capital reduces bank credit extensibility, hence investment. The latter extends the distance between the competitive economy and the Pareto frontier. The Ramsey planner internalizes pecuniary externalities, since its constraints include the equilibrium relation between the price of physical capital and aggregate investment. For this reason the planner chooses a lower leverage ratio, hence a higher capital requirement, thereby reducing the run probability. Additionally, by acting under commitment, the planner holds an additional precautionary motive, hence he raises the requirement in booms in anticipation of losses in future recessions.

Next, analytically and numerically I show that liquidity regulations have a distinct role than capital regulations. Given the distribution of asset shocks in the model three regions emerge, a super-solvency region, an insolvency region and a region in which the bank is solvent, but illiquid[4]. The ex ante distinction between an illiquidity-solvency and an insolvency region provides scope for different, complementary regulations. Specifically, liquidity regulations provide readily available cash holdings that reduce ex post the extent of the runnable liabilities, hence the illiquidity region

[4] In this region depositors may run if they fear moral hazard from bank managers, and the latter would loose their share of projects' returns. In equilibrium bank managers' incentives are disciplined by the threat of a liquidity run and a unique shock threshold, which determines the run probability, arises.

even when the bank is solvent. However, they do not modify ex ante managers' incentives toward setting lower leverage, nor the credit capacity of the bank. Equity requirements instead represent un-redeployable liabilities, which cannot be used to reduce the runnable ones. By tightening the run constraint, they effectively promote managers' incentives to set lower leverage, hence reducing the scope for insolvency ex post. In sum liquidity requirements operate on the illiquidity region, while equity requirements operate on the insolvency region.

At last, I address the inter-play between policy announcements and agents/banks expectations. Banks optimally modify their funding structure in response to announcements and this might impair or modify the effects of regulations. This aspect is especially relevant in the case of the Basel accords, which are formally adopted by different countries at later and non-overlapping dates. To answer this question I experiment and compare shifts across Basel regimes when agents attach different probabilities to the occurrence of a regime change. A non-linear announced shift[5] from Basel I to Basel II during a boom, amplifies the leverage build-up, the more so the higher the probability that bankers attach to the regime change. Basel II requires banks to increase equity capital in recessions. Against this prospect banks rationally magnify the increase in leverage during booms to counteract the upcoming restriction. The more so the higher the credibility of the announcement. This has two important implications. First, it suggests that the shift to Basel II might have contributed to the leverage build-up observed in the 2007. Second, it shows that, in choosing the optimal degree of policy cyclicality, regulators shall internalize these anticipatory effects. Reassuringly, the shift from Basel II to Basel III hampers the build-up of leverage.

The rest of the paper is structured as follows. The next sub-session discusses the relation to the literature. Section 2 describes the model, the transmission mechanism and its empirical validity. Section 3 is devoted to the optimal design of prudential regulation. Section 4 examines the distinct roles of equity and liquidity regulation. Section 5 analyzes the announcement effects. Section 6 concludes.

[5] This is computed numerically by using Markov switching regimes. See Farmer, Waggoner and Zha[18].

1.1 Literature Review

This paper relates to a growing literature on macro-prudential regulation under various macro externalities. A first strand of this literature examines pecuniary externalities and incomplete markets when financial constraints depend on market prices[6]. A second strand of the literature focuses on aggregate demand externalities, also in the presence of nominal rigidities[7]. In most cases macro-prudential regulation takes the form of taxes. A distinctive feature of this paper, contrary to past literature, is the design of such regulations in a macro model embedding modern banking featuring information-based bank runs. The paper shows that, even when runs and contractual agreements are privately efficient, the emergence of technological and pecuniary externalities rationalizes the use of equity or liquidity requirements. It then takes both an analytical and quantitative approach to study the optimal level and cyclicality of regulation.

Past literature studying regulations has also largely focused on capital requirements, while the consequences of liquidity requirements[8] are still rarely examined[9]. The rationale and scope for such regulations, on top and above the equity requirements, materialize only in context where there is a marked distinction between insolvency and illiquidity-solvency.

To study prudential regulation I employ a dynamic macro model with bank runs[10], that follow the tradition of fundamental or information-based runs[11]. Like-wise in the class of micro models for information-based runs, the probability of a run endogenously depends upon a signal on

[6] See Lorenzoni [34], Bianchi [7], Bianchi and Mendoza[9].

[7] See Schmitt-Grohe and Uribe [41], Farhi and Werning[17], Korinek and Simsek[33]. Benigno at al.[6] focus on the open economy dimension.

[8] In 2013, the Basel Committee on Banking Supervision agreed on a Liquidity Coverage Ratio (LCR). I focus on that.

[9] Exceptions include Rochet and Vives[38], Vives[44], Santos and Suarez[39] who use static banking models and Bianchi and Bigio[8] who consider liquidity coverage ratios in a model with banks' liquidity management.

[10] The banking sector is modelled along the lines of Angeloni and Faia[1], who introduced information-based bank runs into a macro model with sticky prices to study the role of monetary policy and its interaction with bank capital policies. Gertler and Kiyotaki[21] is macro model which introduces liquidity based bank runs a' la Diamond and Dybvig.

[11] See Allen and Gale[2], Rochet and Vives[38] or Diamond and Rajan[11], [12], [13]. All are static partial equilibrium banking models. Donaldson and Piacentino[14] have recently rationalized the endogenous emergence of fragile banking with the demand of bank debt as means of payment.

banks' balance asset returns[12]. Following the asset shocks three situations materialize: insolvency, illiquidity-solvency and solvency. In models with global games[13], the illiquidity region, which leads to multiplicity of equilibria, vanishes for signals with high precision. In my model the threat of a run when the bank is solvent, serves the purpose of disciplining bank managers. In equilibrium, whereby incentive-compatibility is enforced, the unique shock threshold identifies the run-insolvency region. This feature distinguishes the contractual approach to information-based runs, considered in this paper, from the global-game approach.

My model features a risk-taking channel as banks have an incentive to build-up leverage in face of low interest rates or in booming economies[14]. Various authors have discussed the importance of this channel in the development and unfolding of financial crises[15]. The ability to replicate such channel and to match various moments of macro and banking variables make the model well suited for the analysis of prudential policy.

At last, this paper also connects to the literature examining the role of banks as delegated monitors. Bank managers' moral hazard is disciplined by allowing them to participate to the division of the surplus only if they exert enough effort to re-deploy the projects in full. The threat of exclusion serves to discipline incentives[16]. I indeed show that it is equivalent to the enforcement of an incentive-compatibility constraint.

2 The Model

The model economy is populated by two set of agents, risk-averse households and risk-neutral bank capitalists. Households consume, work and hold uninsured bank short-term liabilities, or

[12] See for instance Gorton[22].

[13] See Rochet and Vives[38] among others.

[14] The focus of this paper is on risk-taking on the liability side. A recent model of risk-taking on the asset side is Gupta[26].

[15] See Hanson, Kashyap and Stein[27] among others. Evidence for risk-taking channel is found in Jimenez, Ongena, Peydro, and Saurina[29], who build on the on bank lending literature initiated by Kashyap and Stein[30].

[16] See Diamond and Rajan[11], [12] and [13] and Gale and Vives[20] for the discipline role of demand depositors on bank managers. Grossman and Hart[24] also previously noted that the threat of bankruptcy and loss of private bene can enforce managers' efforts. See also Sappington[40] for managers' contracts enforcement.

demand deposits, receiving a premium for the loss given default due to a run. Bank capitalists, or bankers, are finitely lived agents who invest in bank equities. The latter pay higher returns since in the event of a run they bear losses. Depositors and bank capitalists have limited abilities in re-deploying projects, hence they delegate this activity to bank managers. Their special re-deploying abilities creates scope for intermediation. Bank managers employ the funds, from depositors and bank capitalists, into investment projects whose returns are subject to idiosyncratic shocks. Once the project's uncertain outcome is realized, bank capitalists claim the residual after depositors are paid out. Upon a bargaining agreement that assign a share of the projects' returns to bank managers, the latter also choose the bank capital structure by maximizing their overall return, conditional on the run probability[17]. The optimal capital structure trades-off the risk of run against the higher costs of bank capital. Bank managers' incentives are disciplined by the threat of a run in the interim period. Even if the bank is solvent, when financiers fear bank managers' moral hazard, they threaten to liquidate by themselves, hence receiving only a fraction λ, but withholding managers' compensation.

Aggregate investment determines physical capital accumulation, which is then used as input, alongside with labour, in the production sector. Investment is subject to adjustment costs, which induce variable price of capital. In the event of a run, early project liquidation entails resource costs. The aggregate fall in investment, which results from the liquidation costs, induces falls in the price of capital. Importantly, while bank managers internalize the bank costs from early liquidation, they fail to internalize the aggregate change in the price of capital. Pecuniary externalities arise due to run constraint on bank short term funding. In the event of a run higher equity capital is needed to cover losses. The ensuing increase in the cost of capital reduces bank credit extensibility, hence investment.

[17]Bank managers get a share of the total return, which is proportional to his bargaining power.

2.1 Households-Investors of Short-Term Liabilities

The economy is populated by a fraction η of households who consume, save and work. They are patient and risk-averse. Households maximize the sum of discounted utilities:

$$\mathbb{E}_0 \left\{ \sum_{t=0}^{\infty} \beta^t U(C_t^h, \omega^1 N_t^{h,1} + \omega^2 N_t^{h,2}) \right\} \tag{1}$$

where $\mathbb{E}_0$ denotes the conditional expectation operator at time $t = 0$, C_t^h denotes households consumption and $\omega^2 N_t^{h,1}$ denotes labour hours supplied in the production sector and $\omega^2 N_t^{h,2}$ denote labour hours supplied in the intermediation sector. The weights ω^i are the preferences weights for each type of job. Labour supply in the two sectors earns respectively wages W_t^1, W_t^2. They will determine which fraction of the households' member will be working in each sector. Households saving decisions are then made on the pooled earned incomes. Households invest in bank's demand deposits D_t[18], which pay an ex ante contractible gross risk-free return R_t one period later. Due to the possibility of bank runs, the ex post return on deposits is subject to a time-varying risk, which grants a premium for loss given default[19]. Hence the ex post return is $R_t^d = \frac{R_t}{(1-\phi_t g_t)}$, where ϕ_t is the probability of run and g_t, the loss given default on risky deposits. Both ϕ_t and g_t are derived in Appendix 7 by taking into account the optimal banks' balance sheet structure derived in section 3.6. Both . The budget constraint reads as follows:

$$C_t^h + D_t \leq W_t^1 N_t^{h,1} + W_t^2 N_t^{h,2} + \frac{R_{t-1}}{(1-\phi_{t-1} g_{t-1})} D_{t-1} \tag{2}$$

Households choose the set of processes $\{C_t^h, N_t^{h,1}, N_t^{h,2}\}_{t=0}^{\infty}$ and deposits $\{D_t\}_{t=0}^{\infty}$, taking as given the set of processes for prices $\{W_t^1, W_t^2, R_t\}_{t=0}^{\infty}$ and the initial value of deposits D_0 so as to maximize 1 subject to 2. The following optimality conditions hold:

$$U_{C^h,t} = \beta \mathbb{E}_t \left[U_{C^h,t+1} \frac{R_t}{(1-\phi_t g_t)} \right] \tag{3}$$

[18] Households are risk-averse, hence they have a preference for investing in redeemable assets such as deposits, as opposed to bank equities which are subject to losses in the event of bank insolvency.

[19] The model can be easily extended to the case in which households lend to money market funds, which in turn invest in banks' short-term bank liabilities. In this case the decision to run is made by money market funds.

$$W_t^1 = -\frac{\omega^1 U_{N^{h,1},t}}{U_{C^h,t}}; W_t^2 = -\frac{\omega^2 U_{N^{h,2},t}}{U_{C^h,t}} \tag{4}$$

Equation 4 gives the optimal choice for labour supply respectively in the production and the intermediation sectors. Equation 3 gives the Euler condition with respect to the bank's demand deposits. Optimality requires that the first order conditions and No-Ponzi game conditions are simultaneously satisfied.

2.2 Bank Capitalists and Intermediary Asset Pricing

A fraction $(1-\eta)$ of the population are risk-neutral finitely lived bankers, with a probability of exiting business of $(1-\theta)$[20]. They consume and invest in equity capital. Bank capital accumulates by re-investing past returns. In every period exiting bankers, a fraction $(1-\theta)$, are replaced by new entrants so that the population is balanced in every period. Risk-neutrality serves the purpose of making those agents willing to invest in a riskier asset, like equity capital[21]. The latter in turn delivers higher returns than deposits to compensate for the losses borne by equity holders in the event of a bank run[22]. Let's define υ_t^b as the stochastic marginal value of old bankers' wealth. This also corresponds to the shadow value of the intra-temporal budget constraint, weighted by the marginal utility which, given risk-neutrality, is equal to one. Bankers receive returns, R_t^b, net of returns paid to depositors, only in the event of no run, hence with probability $(1-\phi_t)$. The exact specification of R_t^b is in section2.3.2.

In every period, while in business, the banker has the choice to allocate each unit of wealth between consumption or saving. Upon retirement the banker can still save or consume. Given the small probability that he will ever become banker again and the impatience, the optimal solution

[20] With a discount factor of $\beta\theta$ bankers are impatient. For this reason they are unable to accumulate enough wealth to avoid the recourse to short-term liabilities. Bankers are also unable to borrow for consumption purposes, due to the impossibility of pledging future income.

[21] Risk-neutrality, alongside the finitely lived structure, ensures that bankers accumulate returns on equity capital fully and wealth is aggregated only across surviving bank capitalists.

[22] This ranking of assets' returns coupled with bankers' risk-neutrality, which generally commands corner solutions in the portfolio allocation, implies that in equilibrium bankers only invest in equity capital.

implies that all final wealth is consumed. We can then write the following Bellman equation:

$$\upsilon_t^b = (1-\theta) + \theta \max\left[1, \beta \mathbb{E}_t \left\{\upsilon_{t+1}^b (1-\phi_t) R_t^b\right\}\right] \tag{5}$$

The term $\max\left[1, \beta \mathbb{E}_t \left\{\upsilon_{t+1}^b (1-\phi_t) R_t^b\right\}\right]$ reflects the fact that surviving bankers can either consume or re-invest in equity capital. Under the full re-investment path, namely when $\beta \mathbb{E}_t \left\{\upsilon_{t+1}^b (1-\phi_t) R_t^b\right\} > \max\left\{1, \beta \max\left\{\mathbb{E}_t(\upsilon_{t+1}^b (1-\phi_t) R_t^b)\right\}\right\}$, a positive wealth accumulation is guaranteed to arise in every period. Defining, BK_t as the aggregate bank capital supply at time t, along the full re-investment path the bank capital at the beginning of $t+1$ is $BK_{t+1} = \theta[(1-\phi_t) R_t^b Q_t L_t]$, where L_t are the bank loans or assets. Aggregate consumption, C_t^b, is given by the consumption of all retired bankers and is given by $C_t^b = (1-\theta) BK_t$. Forward substitution of equity holders value function 5 delivers the intermediary asset or equity price:

$$\upsilon_t^b = \left[\sum_{j=0}^{\infty} ((1-\theta) + (\theta\beta)^j \upsilon_{t+j}^b (1-\phi_{t+j}) R_{t+j}^b\right] \tag{6}$$

The intermediary asset price, equation 6, depends upon the exit rate of equity holders, θ. As the fraction of equity holders falls, the supply of funds declines and so does the asset price. Second, as the probability of bank runs increase, ϕ_{t+j}, today or in all future periods, equity investors anticipate larger discounted losses, hence their evaluation of equity falls and they require higher returns. This observation will prove useful later on. In the competitive economy the run probability is higher than in the planner allocations. This implies a higher cost of equity capital for the competitive economy, hence a lower availability of bank funds for investment. At last, bank equity prices depend upon the returns accruing to equity holders R_{t+j}^b. Further below (see equation **??**) it is shown that those depend negatively upon the bargaining power of the bank managers. The higher is the rent that the bank manager can extract, the lower are the returns accruing to equity holders.

2.3 Intermediation Sector and Information-Based Bank Runs

Depositors and bank capitalists, namely outside financiers, have limited re-deploying abilities, hence they delegate this activity to a bank manager. The latter acquires special re-deploying abilities by acting as a relationship lender. If outside financiers liquidate the project they are able to extract only a fraction $0 < \lambda < 1$ of the liquidation value, while the bank manager can re-deploy its full value. The parameter λ measures the cost of fire sales in the secondary markets for bank assets[23]. Alternatively λ can be interpreted as the liquidity premium that markets require to lend on short-notice[24]. As such λ represents the outside option of the outside financiers, namely how much they would get in absence of the bank managers.

Bank managers employ funds from external financiers to invest in un-correlated investment projects, whose total size is L_t. Each project size is normalized to unity (one machine) and its price is Q_t. Total bank loans, which equal total value of physical capital, $Q_tL_t = Q_tK_{t+1}$, are equal to the sum of deposits (D_t) and bank equities (BK_t). The aggregate bank balance sheet is[25] $Q_tL_t = D_t + BK_t$. The return of the project for the bank is equal to R_t^A, plus a random shock x_t, with density function $f(x_t)$ and cumulative distribution function $F(x_t)$, over a support $[-h, h]$[26]. The variable x_t captures public signals upon which holders of short-term liabilities can coordinate. The demandable nature of deposits creates a collective action problem that exposes the bank to runs as soon as depositors receive news that the payoff from the project is insufficient to reimburse all of them. In the event of a run individual depositors are paid in full as they come to the bank for withdrawal, bank capitalists are rewarded pro-quota after all depositors are served and early project liquidation entails a resource cost $1 > c \geq 0$. Given the bank's fragility, the optimal capital structure shall trade-off the risk of runs against the higher costs of equity capital. Upon a bargaining

[23] See Flannery[19] for an explanation based on adverse selection.

[24] See Diamond and Rajan[11] or Rochet and Vives[38]. In face of early withdrawals banks might seek liquidity in interbank markets.

[25] Banks individual subscripts are omitted, since linearity and the uncorrelated nature of the shocks to aset returns implies aggregation.

[26] The density can have a finite or an infite support. It is only required to have a decreasing hazard rate.

agreement with outside financiers, the bank manager chooses the optimal capital structure in the form of a leverage ratio $d_t = \frac{D_t}{Q_t L_t}$ to maximize their total expected surplus. Within each period the following timing of events holds. At the beginning of time t, the bank manager optimizes the capital structure, collects the funds, lends, and then the project is undertaken. At the end of time t, the project's outcome is known and payments to depositors and bank capitalists, including the fee for the bank manager, are made. A new round of projects starts.

2.3.1 Surplus to Financiers Conditional on Run - Insolvency and Illiquidity

The optimal capital structure is chosen to maximize financiers total surplus. To derive it we shall derive the allocation of returns conditional on whether the bank is solvent, whether the run occurs for sure due to bank insolvency or whether it occurs in the interim period due to banks' illiquidity. Bank managers' incentives are disciplined by the threat of a run in the interim period. Even if the bank is solvent, when financiers fear bank managers' moral hazard, they threaten to liquidate by themselves, hence receiving only a fraction λ, but withholding managers' compensation. Later on it is shown this mechanism implicitly fulfills the managers' incentive compatibility constraint. In an equilibrium in which incentives are correctly enforced, the illiquidity region vanishes and a unique threshold divides the run from the no-run region[27].

Insolvency region. This case materializes when financiers observe a signal on asset shock, for which end of period returns are too low even if liquidated by the bank manager. This translates into the following condition $(R_t^A + x_t)Q_t K_{t+1} \leq R_t D_t$. Writing the condition in terms of the leverage ratio delivers the insolvency threshold:

$$\widetilde{x}_t = R_t d_t - R_t^A \tag{7}$$

In this case payoffs are distributed as follows. Capitalists receive the leftover after depositors are served, so they get zero in this case. To participator in the contract, depositors shall receive at

[27] This uniqueness is akin to the one obtained when runs are modeled through global games. See Rochet and Vives[38]. In that case the coordination on the unique threshold is achieved under the appropriate Bayesian updating. In my model instead threshold uniqueness is rationalized through bank managers enforcement.

least the returns under autarky, that is the case in which they liquidate the projects by themselves extracting the fraction $\lambda(1-c)(R_t^A + x_t)$. Depositors claim this amount in full. The remainder $(1-\lambda)(1-c)(R_t^A+x_t)$, which is extracted by the bank manager at the end of the the period, is shared between depositors and the bank manager based on their relative bargaining power, ξ. Given all of the above total expected returns to outside financiers is $\int_{-h}^{\tilde{x}_t} [1-\xi(1-\lambda)]\,(1-c)(R_t^A + x_t)f(x_t)dx_t$.

Illiquidity region: In this case the asset return shock is such that the bank is solvent if the bank managers re-deploys the assets, hence it satisfies $R_t d_t \leq (R_t^A + x_t)$, but would be insolvent if financiers do so. If financiers fear bank managers' moral hazard they can threaten a run in the interim period. As we shall see later such a threat allows financiers to enforce incentive-compatibility on bank managers. In this case depositors receive the amount $\lambda(R_t^A + x_t)Q_t K_{t+1}$, which is lower than the returns on short-term liabilities. To sum up in this region the shock satisfies the following condition $\lambda(R_t^A + x_t) < R_t d_t \leq (R_t^A + x_t)$. This leads to the following illiquidity threshold:

$$\hat{x}_t = \frac{R_t d_t}{\lambda} - R_t^A \tag{8}$$

In this case, the capitalists alone cannot avoid the run. In equilibrium the bank manager shall intervene to re-deploy assets and avoid the run, so that depositors are paid in full, $R_t d_t$. The remainder is split the bank manager and the bank capitalists according to their relative bargaining power, $\xi(R_t^A + x_t - R_t d_t)$ going to managers and $(1-\xi)(R_t^A + x_t - R_t d_t)$ going to capitalists. Total expected payment to outside financiers is $\int_{\tilde{x}_t}^{\hat{x}_t} \left[(1-\xi)(R_t^A + x_t) + \xi R_t d_t)\right] f(x_t)dx_t$.

Solvency region. In this case the asset shock is so high that the bank is solvent even if all depositors run the bank and liquidate projects by themselves. This happens when $R_t d_t \leq \lambda(R_t^A + x_t)$. Depositors are paid in full and get $R_t d_t$. The bankers could decide to liquidate the project alone and still avoid the run, thereby getting $\lambda(R_t^A + x_t) - R_t d_t$. Hence, they participate if they extract at least this amount. The bank manager can extract the full net amount, $(R_t^A + x_t) - R_t d_t$. The additional surplus is $(1-\lambda)(R_t^A + x_t)$ and it can then be split with bank capitalists according to the bargaining shares. The manager gets $\xi(1-\lambda)(R_t^A + x_t)$. Total payment to outsiders is $\left\{(1-\xi(1-\lambda))\left[R_t^A + x_t\right]\right\}$[28]. Total expected end of period payment to outsider financiers in this case is: $\int\limits_{\hat{x}_t}^{h} \left\{(1-\xi(1-\lambda))\left[(R_t^A + x_t)\right]\right\} f(x_t)dx_t$.

Given the above three cases we can now write the total expected surplus over all possible contingencies as:

$$\left\{ \begin{array}{c} \int\limits_{-h}^{\tilde{x}_t} \left[1-\xi(1-\lambda)\right](1-c)(R_t^A + x_t)f(x_t)dx_t + \int\limits_{\tilde{x}_t}^{\hat{x}_t} \left[(1-\xi)(R_t^A + x_t) + \xi R_t d_t\right] f(x_t)dx_t + \\ + \int\limits_{\hat{x}_t}^{h} \left\{(1-\xi(1-\lambda))(R_t^A + x_t)\right\} f(x_t)dx_t \end{array} \right\} \tag{9}$$

The bank manager chooses the leverage ratio d_t by maximizing 9 subject to the **??** constraint. Asset returns, R_t^A, can be written as a sum of future discounted capital gains through the recursive solution of 11. Hence the above total surplus is also the sum of the future discounted capital gains accruing to financiers.

Proposition 1. *The global maximum for the deposit ratio falls into the region* $\lambda(R_t^A + h) < R_t d_t < R_t^A + h$*, and reads as follows:*

$$d_t = \frac{1}{R_t} \frac{\xi(1-F(\tilde{x}_t))}{\left[\xi(\lambda-1)(1-c)-1\right] f(\tilde{x}_t)} \tag{10}$$

In this region either a run takes place for sure or it does not take place.

Proof. See Appendix 9.

The optimal leverage ratio trade-offs the risk and private cost of a run against the higher costs of equity capital. Given 10 we can discuss some partial equilibrium channels of the model. First, a fall in R, holding all else constant, increases leverage and the run probability. This is so since the run constraint becomes looser and bank manager optimally increases leverage. This captures well the build-up leverage observed prior to the most financial crises. Next, an increase in c reduces deposits since it increases the private costs of runs, which are internalized by the

[28] Importantly notice that payment to bank managers is lower than payment to bankers.

bank managers. An increase in λ, can have ambiguous effects. On the one side, a raise in the outside option, reduces the contractual rents of outside financiers, hence the cost of bank funding. Bank managers can leverage more and the ex post run probability raises. On the other side, the illiquidity region, that serves to discipline bank managers, expands. This induces bank managers to reduce leverage. Which of the two effects prevails also depends upon the general equilibrium spillovers. At last, an increase in h, by expanding the support, produces a mean preserving spread shift in the distribution. This has two effects. On the one side, it increases the density mass on each event x_t below the run threshold, hence it increases the expected run loss. This would induce bank managers to leverage less. On the other side, a shift upward of the support increases the bankers' expected rents. Given the increase in the cost of equity capital, it is generally optimal to increase the share short-term funding, d_t. Once again which of the two effects prevail depends upon the general equilibrium spillovers.

Given the optimal deposit ratio the ex post probability of bank runs (bank risk) reads as follows $\phi_t = \int_{-h}^{\widetilde{x}_t} f(x_t)dx_t = F(\widetilde{x}_t)$[29]. The latter evolves with $\widetilde{x}_t$, hence it endogenously depends upon the macroeconomic fundamentals and upon banks' balance sheet conditions. At last, given the expression for the deposit ratio, and knowing that in aggregate bank's assets amount to Q_tK_{t+1}, we can write the total amount of deposits in the economy as $D_t = d_t^*Q_tK_{t+1}$ and aggregate bank capital as $BK_{t+1} = (1 - d_t^*)Q_tK_{t+1}$. At last, we can derive total returns to bank capitalists which are $R_t^b = \int_{\widetilde{x}_t}^{h} \left\{(1 - \xi(1 - \lambda)) \left[(R_t^A + x_t) - R_t d_t\right]\right\} f(x_t)dx_t$.Note that this expression considers only the no-run state. If a run occurs the capitalist receives no return.

2.3.2 Good and Capital Production Sectors and Market Clearing

The economy comprises a good and a physical capital production sector. Derivations can be found in Appendix 8. The good production sector is competitive and uses an homogeneous of degree one

[29] Note that deposits can never fall below the level where a run becomes impossible. Hence ϕ_t is always positive. Some degree of bank risk is always optimal in this model as it disciplines bank managers.

technology with capital and labour, namely $Y_t = F(N_t^1, K_t)$. Physical capital is rented out to the good-production sector from the capital producers. The latter face adjustment costs in investment, so that physical capital evolves according to $K_{t+1} = (1-\delta)K_t + I_t - \Phi\left(\frac{I_t}{K_t}\right)K_t$, where $\Phi\left(\frac{I_t}{K_t}\right)$ are the adjustment costs. The first order condition with respect to investment delivers an expression for the variable price of capital $Q_t = \Phi'(\frac{I_t}{K_t})$. The latter captures the essence of the macro pecuniary externalities. A run at time $t-1$ induces early projects liquidation with an aggregate resource cost of the magnitude $Q_{t-1}K_tc$. The ensuing fall in investment induces a fall in the asset price at time t through the relation $Q_t = \Phi'(\frac{I_t}{K_t})$. At last the first order condition with respect to future stock of physical capital delivers the aggregate returns on physical capital:

$$R_t^A \equiv \frac{Z_{t+1} + Q_{t+1}((1-\delta) - \Phi\prime(\frac{I_{t+1}}{K_{t+1}})\frac{I_{t+1}}{K_{t+1}} + \Phi(\frac{I_{t+1}}{K_{t+1}}))}{Q_t} \tag{11}$$

where Z_{t+1} is the marginal productivity of capital (see Appendix 8). Equilibrium in the final good market requires that the production of the final good equals the sum of private consumption by households and bankers, investment and the resource costs from the run. The combined resource constraint reads as follows, $Y_t - \Omega_t = C_t^h + C_t^b + I_t$. The term $\Omega_t = \int_{-h}^{\widetilde{x}_t} R_t^A Q_t K_{t+1} c f(x_t) dx_t$, represents the total expected cost of run, which is due to early project liquidation. Market clearing conditions hold in all other markets.

Definition 1. *A competitive equilibrium of the free capital regime is an allocation* $\left\{C_t^h, C_t^h, N_t^{h,1}, N_t^{h,2}, K_{t+1}, I_t, d_t, Y_t\right\}$ *such that for given aggregate shock to productivity,* A_t*, and for given distribution of shocks to bank assets,* $f(x_t)$*, and for given prices of inputs,* $\left\{Q_t, W_t^1, W_t^2\right\}$*: a. Households/investors maximize their utility, hence equations 3 and 4 are satisfied; b. Bankers' value function is maximized, hence equations* $BK_{t+1} = \theta[(1-\phi_t)R_t^b Q_t K_{t+1}]$ *and* $C_t^b = (1-\theta)BK_t$ *are satisfied in the aggregate economy; c. banks' deposit ratios are set so that bank managers' are disciplined and all outside financiers participate to the bank contract, which implies that the deposit ratio is set at the optimal level ratio deposits/project cost as per equation 10; d. physical capital* *producers maximize the future sum of discounted profits, hence equations* $Q_t = \Phi'(\frac{I_t}{K_t})$ *and 11 are satisfied. Finally the resource constraint,* $Y_t - \Omega_t = C_t^h + C_t^b + I_t$, *with the production function* $F(N_t^1, K_t)$, *the capital accumulation equation and the market equilibrium conditions hold.*

2.4 Transmission Channels and Empirical Moments' Matching

Before examining the role of prudential regulation, it is instructive to illustrate and assess the empirical validity of the transmission mechanism in the model. This can be done by simulating the general equilibrium in response to standard macro shocks.

The model's calibration is chosen as follows. The time unit is the quarter. The utility function of households is $U(C_t, N_t) = \frac{C_t^{1-\sigma}-1}{1-\sigma} + \nu \log(1 - N_t)$, with $\sigma = 2$, as in most real business cycle literature. The weight on labour dis-utility, ν, set equal to 2.3 to generate a steady-state level of employment of $N \approx 0.3$. The discount factor, β, is set equal to 0.995, so that the annual real interest rate is around 2%. The production function is assumed to be a Cobb-Douglas, $F(\bullet) = K_t^{\alpha}(N_t)^{1-\alpha}$, with $\alpha = 0.3$. The quarterly aggregate capital depreciation rate δ is 0.025. The density of the bank specific shocks using a uniform distribution[30]. To calibrate h I follow Angeloni and Faia[1] who calculate the average dispersion of corporate returns from the data constructed by Bloom et al. [10], which is around 0.3, and multiply this by the square root of 3, the ratio of the maximum deviation to the standard deviation of a uniform distribution. The result is 0.5. I set the value of h slightly lower, at 0.45, a number that yields a more accurate estimates of the steady state values of the bank deposit ratio. Sensitivity analyses are conducted for all bank parameters. Given the interpretation of λ as a market discount, it can be proxied as the ratio of the interest rate applied to firms' external finance to the money market rate. In the US over the last 20 years, the ratio between the money market rate and the lending rate, based on 30-year mortgage loans, has been around 3 percent. This leads to a value of λ around 0.6. A slightly lower value (0.56) is chosen as this helps to pin down the value of the steady state bank capital. Again sensitivity analysis is

[30] Other distributions with non-decreasing hazard rate deliver similar shape for the total expected returns to outside lenders. Angeloni and Faia[1].

done above and below this value. The banks' survival rate, θ, is set at 0.97, a value compatible with an average horizon of 10 years. Notice that the parameter $(1-\theta)$ is meant to capture only the exogenous exit rates, as the failure rate is linked to the distribution of idiosyncratic shocks to corporate returns. The parameter c can be set by looking at statistics on recovery rates, available from Moody's. These rates tend to vary considerably, from below 50 percent up to 80 or 90 percent for some assets. The chosen benchmark value is $c = 0.15$, which also matches a long run average value of bank capital.

At last productivity shocks evolve according to an AR(1) process, $A_t = A_{t-1}^{\rho_\alpha} \exp(\varepsilon_t^\alpha)$, where $\rho_\alpha = 0.9$ and ε_t^α is an i.i.d. shock with standard deviation $\sigma_\alpha = 0.01$ and government spending evolves according to $G_t = G_{t-1}^{\rho_g} \exp(\varepsilon_t^g)$, where $\rho_g = 0.9$ and ε_t^g is an i.i.d. shock with standard deviation $\sigma_g = 0.02$. Simulations of the competitive economy are based on higher order perturbation methods. Simulations of the non-linear shifts in regimes, from section5, are based on the Markov-switching method from Farmer, Waggoner and Zha[18].

I illustrate the basic transmission channels through impulse responses of selected variables to a 1% positive productivity shock, shown in Figure 1. An expansionary shock which reduces interest rate on short-term funding fosters the build-up of leverage and risk. Since short-term funding is now cheaper, the run constraint is relaxed and bank managers can lever up more (see bottom left panel). Higher leverage brings about a higher probability of run (second panel on the left). The pass-through onto the return on assets (second panel on the right) is partial. As productivity raises, the return on physical capital initially raises, but declines when the price of investment starts to raise. This implies that the bank lending premium, namely the return on short-term funding over the return on assets, falls. Since the bank is now funding extending more credit to investment, all source of bank funding, including equity capital raise (see first panel on the right). However and interestingly, equity capital falls relatively to short-term funding. The bank capital ratio therefore behaves counter-cyclically. Leverage and bank risk pro-cyclicality as well as bank

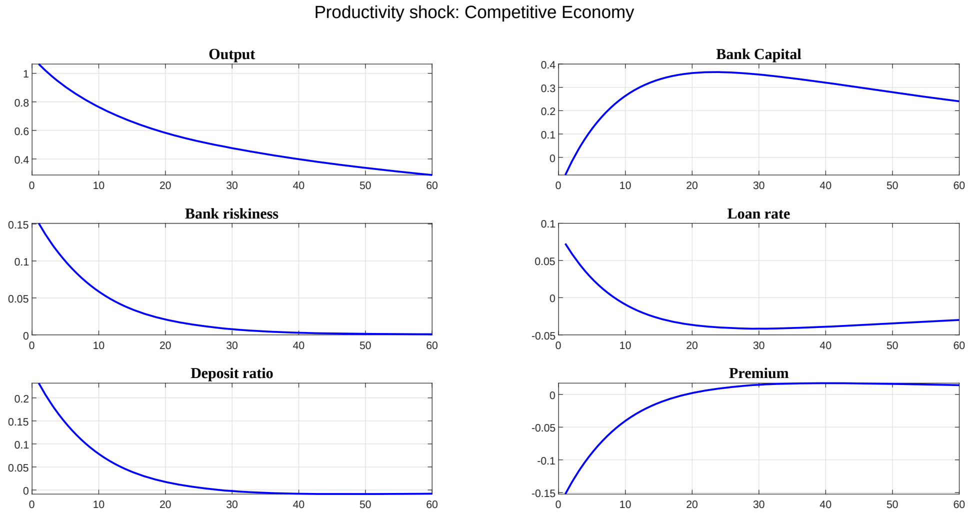

Figure 1: Impulse response of selected variables to a positive productivity shock in the competitive economy.

capital ratio counter-cyclicality are in line with most evidence in banking[31] and with most models of bank delegation[32]. The rest of the macro variables have a very predictable behaviour with output, investment, physical capital and asset prices booming.

Next, to further assess the model's empirical validity, Table1 shows volatilities and persistence of selected macro and banking variables in the model and in the data. Here simulations are in response to both a productivity and a demand shock, the latter taking the form of a government spending shock.

The model matches well volatilities of the main macro variables and of the main banking variables. Description of the data used is in Appendix[?]. The volatilities of the deposit and loan rates are slightly lower than the ones observed in the data. This is understandable since prices in the retail intermediation market are also affected by other channels, such as endogenous competition.

[31] See Gorton and Metrick[23] or Jimenez, Ongena, Peydro, and Saurina[29] among many others.
[32] See Repullo and Suarez[37] among others.

Table 1: **Second moments and persistence of selected variables in the model and in the data for the US and Europe.**

	Model		US		Euro Area	
	St. Dev.	Persistence	St. Dev.	Persistence	St. Dev.	Persistence
Consumption	0.99	0.98	0.80	0.87	0.60	0.90
Employment	2.6	0.94	2.40	0.90	2.36	0.85
Investment	0.56	0.98	0.72	0.92	0.42	0.94
Deposit Rate	0.31	0.97	0.42	0.86	0.50	0.89
Loan Rate	0.36	0.97	0.51	0.83	0.40	0.90
Bank Risk - Porb of run	0.36	0.92	0.36	0.67	0.31	0.50

The persistence of bank risk seems instead to be slightly higher than in the data.

3 Prudential Regulation

Prudential regulation is justified in presence of macro externalities. Enforced contractual agreements are generally privately efficient and this is the case here as well, as shown below. Beyond that, information-based bank runs are generally intended as a device to enforce market discipline. Despite private efficiency, however social inefficiencies, in the form of technological and pecuniary externalities, may arise. This provides a rationale for prudential regulation. The next section shows the emergence of such externalities by comparing the competitive allocation, respectively to one chosen by an efficient planner and to the one chosen by a Ramsey planner. The first only internalizes technological constraints, hence its comparison with the competitive allocation allows me to identifies the conditions under which technological inefficiencies may arise. The second planner internalizes the competitive economy implementability conditions, including the response of market prices. Hence the comparison of the Ramsey plan with the competitive allocation allows me to discus the nature of the pecuniary externalities arising in this model.

On a technical note, it shall be considered that the Ramsey planner necessitates an instrument to implement the constrained optimal allocation. For this reason, and prior to the outline of the

Ramsey plan, this section shows how minimum regulatory equity requirements can be introduced in the model. I choose to start the design of optimal regulation with equity requirements, rather than with liquidity ones, the reason being that under the Basel Accords the first have prescribed cyclicality. The optimal design of the cyclical properties of regulation is one of the goals of this paper.

3.1 Private versus Social Efficiency

Hereby it is shown that the decision to run and the contractual agreement between bank managers and financiers is privately efficient. Notwithstanding, a comparison with the socially efficient allocation reveals that the equivalence with the competitive economy is guaranteed only under certain conditions.

3.1.1 Incentive Compatible Delegation Contracts and Privately Efficient Runs

The delegation problem between the outside financiers and the bank manager naturally entails a moral hazard problem. The contractual relation between the bank manager is privately efficient if managers' incentives are disciplined in first order stochastic dominance and in second order stochastic dominance. First, the participation of the manager to a share of the surplus disciplines his incentives in first order stochastic dominance, namely in achieving the maximum expected returns. However, the incentives to minimize the risk of run are enforced by a remuneration scheme that satisfies an incentive compatibility constraint[33]. Below I show formally that the threat of a run in the interim period achieves this result and disciplines the manager. This is shown in proposition 2 below.

Proposition 2. *A bank manager remuneration fee proportional to the expected projects return and the threat of a run in the interim period, with exclusion from surplus sharing, are sufficient and necessary conditions to implement incentive compatible delegation contracts under the optimally*

[33] See Diamond and Rajan[11], [12] and [13] and Gale and Vives[20] for the discipline role of demand depositors on bank managers. Grossmann and Hart[24] and[25] also noted that the threat of bankruptcy and loss of private bene can enforce managers' efforts. See Sappington[40] for the conditions of managers' contracts enforceability;.

chosen leverage ratio.

Proof. Depositors threaten a run, even when the bank is solvent, but fear managers' moral hazard, when the shock on asset falls in the region $x \in \left[\widetilde{x}, \hat{x}\right]$. The expected total fee to the bank manager, which we label as χ, when this region is not nil is:

$$\begin{aligned}\chi_t &= F(\widetilde{x}_t)\left[\xi(1-\lambda)(1-c)(R_t^A+x_t)\right]+ \\ &+(F(\hat{x}_t)-F(\widetilde{x}_t))\left[\xi((R_t^A+x_t)-R_td_t)\right]+ \\ &+(1-F(\hat{x}_t))\left[\xi(1-\lambda)(R_t^A+x_t)\right]\end{aligned} \tag{12}$$

If the manager exerts effort and minimizes run risk, his total expected fee reads as follows:

$$\varkappa_t = F(\widetilde{x}_t)\left[\xi(1-\lambda)(1-c)(R_t^A+x_t)\right]+(1-F(\widetilde{x}_t))\left[\xi((R_t^A+x_t)-R_td_t)\right] \tag{13}$$

The above remuneration materializes when the illiquidity region vanishes and when in the solvency region bank managers always liquidate projects on behalf of capitalists. The bank manager incentive to minimize risk are enforced when the fee under 12 is lower than the fee under 13. This incentive compatibility constraint is satisfied for any value of x_t if and only if:

$$\lambda(R_t^A+x_t) < R_td_t \tag{14}$$

The last condition is satisfied under the optimal deposit ratio, which based on Proposition 1, falls in the region $\lambda(R_t^A+x_t) < R_td_t < R_t^A+x_t$. *Q.E.D.*

In equilibrium if the run threat is credible bank managers incentive compatibility is enforced and the cumulative probability of an interim run goes to zero or alternatively the illiquid-solvent region vanishes. This ensures that in equilibrium a unique threshold between the super-solvency and the insolvency region emerges. Note however that the ex ante possibility of such an illiquid-solvent region is useful to discuss the distinct roles of different regulations. Section4.1.1 shows that equity and liquidity requirements operate differently on the illiquidity-solvency and on the insolvent regions.

3.1.2 Social Efficiency and Technological Externalities

Here the competitive economy, whereby a bank managers conduct the projects- re-deploying activity against a bargained fee, is compared to an efficient plan, whereby a benevolent planner redeploys projects at the expense of some technological costs.

The social planner chooses the real allocation of the economy and the optimal leverage ratio by maximizing the sum of utilities of all financiers, subject to the technological constraints and in absence of market prices. The planner re-deploys projects' returns on behalf of financiers, who, like before, have limited re-deployment abilities, and rebates the proceeds to them in units of consumption goods. Hence the resource constraint includes the proceeds from the good-production technology and the proceeds from the capital investment and re-deployment activity. The planner also satisfies the service constraint, so that the proceeds from projects' liquidation are rebated to depositors first. Projects returns are net of the liquidation cost, c, in the event of a run. While the bank manager receives a compensation, the planner's re-deploying activity is conducted benevolently and entails a technological cost, μ, which consists of monitoring and processing projects' information. For ease of exposition I assume that the intermediation sector does not demand labour. The results remain valid upon re-introducing the latter. The planner chooses $\left\{C_t^h, C_t^b, N_t^h, K_{t+1}, I_t, d_t\right\}$ to:

$$Max\ \mathbb{E}_0 \left\{ \eta \sum_{t=0}^{\infty} \beta^t U(C_t^h, N_t^h) + (1-\eta) \sum_{t=0}^{\infty} (\beta\theta)^t C_t^b \right\} \tag{15}$$

$$\text{s. to} \tag{16}$$

$$\begin{aligned} & F(N_t^1, K_t) + \phi_t \left[1 - \mu(1-\lambda)(1-c)(R_t^A + x_t)\right] + (1-\phi_t)\left[(1-\mu)(R_t^A + x_t) + R_t d_t)\right] \\ = \ & C_t^h + C_t^b + K_{t+1} - (1-\delta)K_t + \Phi\left(\frac{I_t}{K_t}\right) K_t, \end{aligned}$$

The above resource constraint, 16, implies that the proceeds from the projects investment and re-deploying activities, are rebated as follows. In the event of a run, which occurs with probability ϕ_t at the end of period t, only depositors are paid. Since the planner has better re-deploying ability, depositors receives an additional return $(1-\lambda)(R_t^A + x_t)$. The latter is net of the early liquidation costs, c, and of the monitoring costs, μ. In case of no run, which occurs with probability $(1-\phi_t)$, and since projects are brought to completion by the planner, depositors receive $R_t d_t$, while bank capitalists receive, $\left[(R_t^A + x_t) - R_t d_t\right]$. The proceeds to bank capitalists have to be netted out of the monitoring costs, μ. In the event of no run total proceeds to outside financiers is $\left[(1-\mu)(R_t^A + x_t) + R_t d_t)\right]$.

The first order condition with respect to the deposit ratio reads as follows:

$$\left[(1-\mu(1-\lambda))(1-c)R_t d_t f(\widetilde{x}_t)\right] R_t - \left[R_t d_t f(\widetilde{x}_t)\right] R_t + \mu R_t \left[1 - F(\widetilde{x}_t)\right] = 0 \tag{17}$$

The above efficiency condition is equivalent to the optimal deposit ratio in the decentralized economy, equation 41, when $\mu = \xi$. Intuitively the decentralized leverage ratio is optimal when the rents extracted by the bank manager are not higher (or smaller) than the technological costs of monitoring and re-deploying project returns. Consider the case in which they are higher than the technological costs of monitoring projects. In this case the bank manager extracts a higher compensation in the run states. Hence his incentives to leverage raise compared to the efficient economy.

3.2 Ramsey Allocation and Pecuniary Externalities

To highlight the role of pecuniary externalities I derive the Ramsey allocation and compare it to the competitive allocation. In the event of a run bank managers internalize their own bank cost of early project liquidation. However they fail to internalize that aggregate liquidation costs induce a fall in investment, which in turn triggers a fall in the price of capital. Pecuniary externalities emerge due to the constraint on short-term funding represented by the run condition. In the event of a run higher equity capital is needed to cover losses. This raises the price of equity capital inducing a wedge between the marginal utility of depositors and bank capitalists. This emerged clearly from the impulse responses of Figure 1 where the higher risk of run induced an increase in equity capital and a fall in the lending premium. The latter implies that the higher return on assets served to cover the higher returns required by bank capitalists. The increased costs of long term funding reduces credit availability and induces further falls in aggregate investment. The latter extends the distance between the competitive economy and the Pareto frontier.

The Ramsey planner internalizes pecuniary externalities, since its constraints include the equilibrium relation between the price of physical capital and investment. The Ramsey regulator is a benevolent planner acting under commitment that maximizes the sum of financiers' future discounted utilities subject to all equations characterizing the competitive economy, including equilibrium market prices. The Ramsey planner implements the constrained Pareto optimal allocation through a policy instrument. I set the policy instrument to be a minimum capital requirement, bk_t^{Min}. Such an instrument has been in place for sometimes following the Basel accords. Moreover recent regulations establish some form of cyclicality of the minimum requirements. The solution to the Ramsey plan allows us to establish the optimal cyclicality of the requirement. Hence, a first step toward the design of the Ramsey plan is to modify the competitive equilibrium in presence of regulatory requirements.

3.2.1 Introducing Regulatory Capital Requirements

To introduce minimum equity requirements I follow the approach outlined in Elizaldea and Repullo[16][34]. They discuss the difference between economic capital, regulatory capital and actual capital. Economic capital is the equilibrium equity capital arising in absence of regulatory regimes, hence the one derived in an unregulated economy. The regulatory capital is the minimum enforced by the regulator. Actual capital is the equilibrium equity capital resulting from the optimization in presence of the regulatory constraint, hence it might include an economic capital beyond the minimum. In other words the minimum requirement might be occasionally binding. First, once regulatory capital, bk_t^{Min}, is introduced, the run constraint shall be modified as follows:

$$(R_t^A + x_t) \leq R_t d_t + bk_t^{Min} \tag{18}$$

Regulatory capital acts as an additional liability, which by artificially expanding the run region,

[34] The approach is later adopted and extended also in Angeloni and Faia[1].

reduces the scope for leveraging. Second, in a competitive environment the regulator sets minimum capital requirements on banks in order to reduce their risk, perceived to be undesirably high under an unregulated regime. The regulator enforces the capital requirement by imposing a penalty on non-compliance[35]. It is assumed that, in case of non-compliance, the regulator adjusts the return to bank capitalists downward, to replicate the return to financiers that, in an unregulated regime, would prevail under a bank run. This implies reducing the overall cost of equity capital, hence increasing the demand of it, by the bank. In case of non-compliance a run does not necessarily occur, because the project outcome may be sufficient to pay depositors, though it is insufficient to comply with the minimum capital ex-post. In this case, the levy generates a cash inflow whose ex-ante expected value is returned to capitalists in form of a transfer. Realistically, the regulator maintains "orderly conditions" in financial markets, by ensuring that the bank run, if it occurs, does not entail social costs (value of $c = 0$). As a result, banks are always capable of recovering the full value of the project. Given this, the adjusted return to the capitalist net of the lump-sum transfer, in case of non-compliance without run, is the difference between the returns he gets with and without bank run[36], which is $\tau_t^{bk} = -(1-\xi)\left[(R_t^A + x_t) - R_t d_t\right] + \left[(1-\xi)(R_t^A + x_t)(1+\lambda) - R_t d_t\right]$. The lump-sum transfer is equal to the expected value, $\int\limits_{R_t d_t - R_t^A}^{R_t d_t + bk_t^{Min} - R_t^A} (1-\xi)\lambda(R_t^A + x_t) + R_t d_t f(x_t) dx_t$, where bk_t^{Min} is the minimum capital ratio set by the regulator. The minimum equity requirement represents the instrument adopted by the Ramsey planner. Conditional on the new run region, 18, the bank manager recomputes the surplus to financiers as follows:

[35] The Basel Committee does not set penalties, but national supervisors choose the enforcing instruments. Those vary both with regard to the nature of the penalties (explicit, implicit or both) and to the degree to which they are set ex-ante and publicly disclosed.

[36] Note that the first term on the LHS is the capitalist return without run (for sufficiently low values of $R_A + x$, in the zone where the bank's intervention is necessary), while the second is equal to the difference betwen the deposit return with and without run. Hence the capitalist is charged also the imputed cost of run for the depositor.

$$\left\{\begin{array}{l} \int\limits_{-h}^{R_t d_t + bk_t^{Min} - R_t^A} \left[1 - \xi(1-\lambda)\right](1-c)(R_t^A + x_t) f(x_t) dx_t + \\ + \int\limits_{R_t d_t + bk_t^{Min} - R_t^A}^{\frac{R_t d_t + bk_t^{Min}}{\lambda} - R_t^A} \left[(1-\xi)(R_t^A + x_t) + \xi R_t d_t\right] f(x_t) dx_t + \\ + \int\limits_{\frac{R_t d_t + bk_t^{Min}}{\lambda} - R_t^A}^{h} \left\{(1 - \xi(1-\lambda))(R_t^A + x_t)\right\} f(x_t) dx_t \end{array}\right\} \tag{19}$$

Solving the integrals as shown in proposition 1 delivers the new leverage ratio and the new bank capital ratio. A closed form solution for both is obtained under a uniform distribution for asset shocks, with the actual deposit ratio being:

$$d_t^E = d_t - \frac{1}{R_t} z_t bk_t^{Min} \tag{20}$$

Hence leverage tends to be lower than in the absence of constraint. The corresponding actual bank capital ratio is $bk_t^E = bk_t + \frac{1}{R_t} z_t bk_t^{Min}$, where bk_t^E is the actual capital and where z_t, which is generally smaller than 1[37]. Hence $bk_t^E > bk_t^{Min}$ unless bk_t^{Min} is much higher than bk_t. If the capital constraint is not too tight, banks will normally maintain extra capital above the minimum. On the other side, when the capital requirement is very high, the ex-ante desired capital ratio tends to fall below the regulatory minimum. In this case the capital requirement may become strictly binding. The bank capital accumulation shall also be modified to take into account the new expected returns to bank capitalists. It now reads as follows:

$$BK_{t+1} = \theta \left\{ \left[\int\limits_{R_t d_t^E + bk_t^{Min} - R_t^A}^{h} \left\{(1 - \xi(1-\lambda)) \left[(R_t^A + x_t) - R_t d_t^E\right]\right\} f(x_t) dx_t \right] Q_t K_{t+1} \right\} \tag{21}$$

Note that the latter reduces to the bank capital accumulation in the unregulated economy for $bk_t^{Min} = 0$[38]. Appendix 11 provides additional details on the probability of bank runs and on the

[37] For the calibration using the uniform distribution it would be $z = \frac{2-(1+\lambda)(1-c)}{3-(1+\lambda)(1-c)}$.

[38] The return to the capitalist should include also the lump-sum transfer from the regulator, not shown in equation 44 for notational simplicity.

bank capital accumulation under this case. The transmission mechanism of the regulated economy is solved numerically to account for the full general equilibirum effects below under the Ramsey plan and under operational rules for regulatory requirements[39]

3.2.2 Ramsey Plan

Definition 2. *A competitive equilibrium of the regulated economy is an allocation* $\left\{C_t^h, C_t^h, N_t^{h,1}, N_t^{h,2}, K_{t+1}, I_t, d_t, bk_t^{Min}, Y_t\right\}$ *such that for given aggregate shock to productivity,* A_t*, and for given distribution of shocks to bank assets,* $f(x_t)$*, and for given input prices,* $\left\{Q_t, W_t^1, W_t^2\right\}$*: a. Households/investors maximize their utility, hence equations 3 and 4 are satisfied; b. Bankers' value function is maximized, hence equations 21 and* $C_t^b = (1-\theta)BK_t$ *are satisfied in the aggregate economy; c. banks' deposit ratios are set so that bank managers' are disciplined and all outside financiers participate to the bank contract, which implies that the deposit ratio is set at the optimal level ratio deposits/project cost as per equation 20; d. physical capital producers maximize the future sum of discounted profits, hence equations* $Q_t = \Phi'(\frac{I_t}{K_t})$ *and 11 are satisfied. Finally the resource constraint,* $Y_t - \Omega_t = C_t^h + C_t^b + I_t$ *with the production function* $F(N_t^1, K_t)$*, the capital accumulation equation and the market equilibrium conditions hold.*

The Ramsey planner chooses a real allocation and the policy instrument. Competitive equilibrium conditions are merged so that remaining prices can be backed using the agents' first order conditions[40]. The objective of the planner is the sum of future expected discounted utility of the households, depositors and bankers in this model. Bankers are risk neutral, hence all is needed is to include their asset accumulation, namely their budget constraint, in the set of competitive equilibrium equations. At last, note that for analytical and computational convenience it is useful to merge the resource constraint, the capital accumulation, the first order condition on investment or asset price, $Q_t = \Phi'(\frac{I_t}{K_t})$, and the return on asset, namely equation 11, into a single technological

[39] The presence of the occasionally binding minimum requirement under the regulated economy modifies the transmission mechanism compared to the free capital regime. For this reason and to guarantee also convergence of the equilibrium, the numerical solution features the following adjusted calibration: $\phi = 3, c = 0.185, h = 0.4, \lambda = 0.45$.

[40] The Ramsey plan is therefore derived through the primal approach.

constraint:

$$F(N_t^{h,1}, K_t) - \int_{-h}^{\widetilde{x}_t} R_t^A \Phi'(\frac{I_t}{K_t}) K_{t+1} c f(x_t) dx_t = C_t^h + C_t^b + K_{t+1} - (1-\delta)K_t + \Phi\left(\frac{I_t}{K_t}\right) K_t \tag{22}$$

where $\widetilde{x}_t = R_t d_t^E + bk_t^{Min} - R_t^A$, $\frac{1}{R_t} = \beta \mathbb{E}_t \left[\frac{U_{C^h,t+1}}{U_{C^h,t}(1-\phi_t g_t)} \right]$ and $R_t^A \equiv \frac{F_K(N_{t+1}^{h,1}, K_{t+1}) + \Phi'(\frac{I_{t+1}}{K_{t+1}})((1-\delta) - \Phi\prime(\frac{I_{t+1}}{K_{t+1}})\frac{I_{t+1}}{K_{t+1}} + \Phi(\frac{I_{t+1}}{K_{t+1}}))}{\Phi'(\frac{I_t}{K_t})}$, $Q_t = \Phi'(\frac{I_t}{K_t})$ and where $N_t^{h,1}$ is solved from 4[41].

Given the above the Ramsey plan can analytically be written as follows: choose $\left\{ C_t^h, C_t^b, N_t^{h,1}, N_t^{h,2}, K_{t+1}, I_t, d_t, Y_t \right\}$ to:

$$Max\ \mathbb{E}_0 \left\{ \sum_{t=0}^{\infty} \beta^t U(C_t^h, \omega^1 N_t^{h,1} + \omega^2 N_t^{h,2}) \right\} \tag{23}$$

subject to the technological constraint, 22, the optimal deposit ratio in the regulated economy, 20, and the bank capital accumulation in the regulated economy, namely equation 21. The resource constraint and the optimal deposit ratio feature expectations. For this reason the allocation is inherently non-stationary at time zero[42]. Stationary is recovered by enlarging the state space with the lagrange multipliers associated with constraints featuring future expectations[43]. First order conditions to the Ramsey plan are summarized by a non-linear system of difference equations. The system is highly non-linear and does lend itself to a simple analytical solution. For this reason the discussion on the properties of the Ramsey plan is done by examining the numerical solution. To best highlight the properties of optimal regulation the next section discusses the comparison between the Ramsey plan and the competitive economy.

[41] The Euler equation can be eliminated from the set of constraint of the primal approach. It can be used in a second step to derive the implied return on deposits given the optimal allocation of consumption.
[42] See recently Khan, King and Wolman[32].
[43] The Lagrange multipliers are set to zero in the first period to guarantee saddle-point optimality.

3.2.3 Quantitative Comparison Competitive Equilibrium - Ramsey Allocation

Figure 2 shows impulse responses to 1% increase in productivity and compares the competitive equilibrium (solid line in each panel) in absence of regulation with the optimal Ramsey plan (dashed line). The divergence between the two provides a measure of the pecuniary externalities that are internalized by the planner. First, the regulator sets lower short-term leverage, hence higher capital ratios, compared to the unregulated economy. This allows the planner to achieve lower probability of runs, hence bank risk. This is so since the planner internalizes the pecuniary externalities. Bank runs entail aggregate liquidation costs, $-\int_{-h}^{\widetilde{x}_t} R_t^A \Phi'(\frac{I_t}{K_t}) K_{t+1} c f(x_t) dx_t$. The latter enter the resource constraint, which is among the planner constraints, but is not observed by bank managers. The aggregate cost of early projects liquidation reduce aggregate investment in the competitive economy, which in turn reduces asset prices, through the adjustment cost elasticity $\Phi'(\frac{I_t}{K_t})$. Interestingly, the premium which is given by the ratio between the return on deposits, R_t, and the return on assets, R_t^A, fluctuates much more under the competitive economy. The return on deposits tracks fluctuations in the marginal utility of depositors across periods. In the competitive equilibrium the fall in the premium is larger, indicating that the loss in depositors' marginal utility is larger.

Second, the Ramsey planner sets pro-cyclical bank capital buffers, likewise in the Basel III regime. Since the planner acts under commitment, it holds stronger precautionary saving motives than bank managers do. For this reason the planner finds optimal to force banks to increase capital buffers in booms, in anticipation of the losses materializing in the upcoming recession.

4 Capital versus Liquidity Requirements

The introduction of new regulations raised the question to as whether additional requirements overlap with the previous ones or tackle different type of risk externalities. The question is especially relevant for the comparison between equity capital and the recently introduced liquidity regulations. The first is generally motivated by the need to reduce leverage, which is achieved by

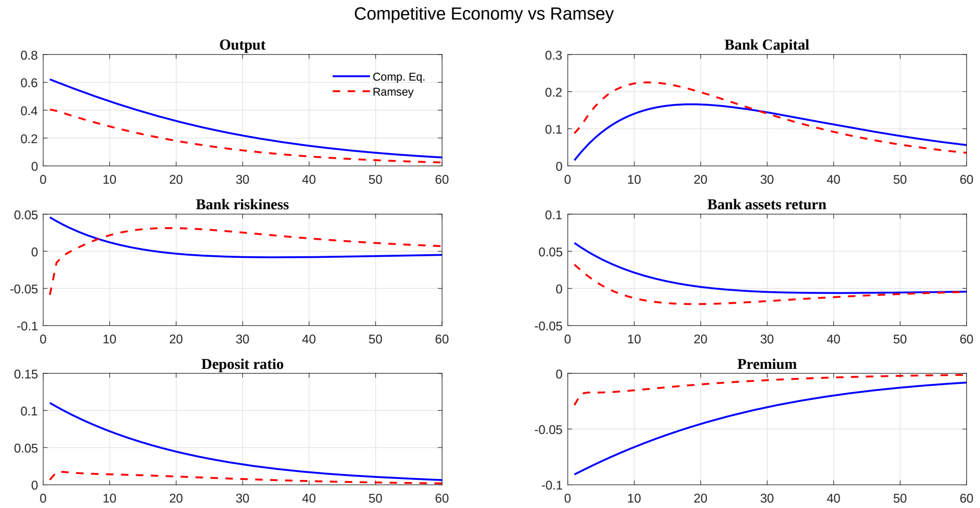

Figure 2: Impulse responses of selected variables to a positive productivity shock comparing the competitive equilibrium and the Ramsey regulator.

curtailing the cost of capital. The regulator, by forcing banks to raise higher capital, induces a dilution effect that trims the returns on equity capital, hence its cost for banks. In this respect minimum equity requirements are akin to taxes on equity holding and have the purpose of modifying incentives to leverage on the margin. On the contrary liquidity requirements substantiate the need to maintain cash buffers in the event of a run or liquidity crises, while leaving unaltered the incentives to leverage and advance credit ex ante. Intuitively equity regulation operate by reducing the extent of bank insolvency, while liquidity regulations are intended to reduce banks' liquidity strains. Since my model features both an illiquidity-solvency and an insolvency region it seems to be an ideal laboratory economy to study the comparative role of the two regulations. There is also an independent interest in studying the consequences of liquidity regulations. While they have yet to be implemented in most countries, little is known about their impact. Past academic literature has studied equity regulations extensively, but almost nothing exists for liquidity regulation.

The comparison between the two can be best understood by confronting two regulated economies, each featuring one of the two requirements. The joint impositions of the two would confound the effects and complicate the identification of how each of them operates. Upon this logic in what follows I further derive the competitive equilibrium when liquidity requirements, in the form of cash buffers, are imposed. I then compare analytically and numerically the two regulated economies, one under equity and one under liquidity requirements.

4.1 Introducing Regulatory Liquidity Requirement

I introduce a regulatory liquidity coverage ratio[44] as indicated in the BIS[5], which implies that banks have to hold a certain percentage of assets as safe and liquid. I define these assets as cash holdings, M[45]. The banks' balance sheet constraint at time t and at all subsequent period now becomes:

$$BK_t + D_t = Q_t K_t + M_t \tag{24}$$

The insolvency region, namely the one of run for sure, reads as follows $(R_t^A + x_t)Q_t K_t + M_t \leq R_t D_t$. Upon expressing in ratios to assets and defining the regulatory liquidity ratio as $m_t^R = \frac{M_t}{D_t}$[46], the solvency threshold can be written as follows:

$$\widetilde{x}_t = R_t d_t - m_t^R d_t - R_t^A \tag{25}$$

All other regions can be adjusted accordingly and by considering that failure takes place only if the residual part, namely the difference between deposits' face value, $R_t D_t$, and cash holdings, falls short of the gross returns on assets. In this case total surplus to outside financiers, net of the fee to the bank managers, reads as follows:

[44] The definition will follow BIS[5], which addresses liquidity risk. Two liquidity ratios are proposed in there, the liquidity coverage ratio and the net stable funding ratio. The first has been implemented in most countries, while the second has not. I'll then focus on the first.

[45] Obviously liquid assets might include other safe assets, as liquid bonds, whose price might vary with market frictions. This aspect is neglected in my analysis as the focus is primarily on how liquidity requirements affect the run region. Adding those considerations would introduce further dimensions to the analysis, but would not alter the basic implications derived here.

[46] This is the exact definition in the BIS [5] document.

$$\left\{\begin{array}{l} \int\limits_{-h}^{R_t d_t - m_t^R d_t - R_t^A} \left[1-\xi(1-\lambda)\right](1-c)(R_t^A + x_t) f(x_t) dx_t + \\ + \int\limits_{R_t d_t - m_t^R d_t - R_t^A}^{\frac{R_t d_t - m_t^R d_t}{\lambda} - R_t^A} \left[(1-\xi)(R_t^A + x_t) + \xi R_t d_t\right] f(x_t) dx_t + \\ + \int\limits_{\frac{R_t d_t - m_t^R d_t}{\lambda} - R_t^A}^{h} \left\{(1-\xi(1-\lambda))(R_t^A + x_t)\right\} f(x_t) dx_t \end{array}\right\} \tag{26}$$

We can once again solve the integrals and study the shape of the surplus function to find the internal maximum for the deposit ratio. To obtain an interpretable closed form solution I employ again the uniform distribution for asset shocks to assets, under which the optimal deposit ratio reads as follows:

$$d_t^m = \frac{d_t}{1 + \Xi_t m_t^R d_t} \tag{27}$$

where $d_t = \frac{1}{R_t} \frac{R_t^A + h}{2 - \lambda + c(1+\lambda)}$ is the leverage ratio under free capital, while $\Xi_t = \frac{2(1-c+\lambda(1-c)) + \left(\frac{m_t^R}{R_t}\right)(\lambda(1-c)-c)}{(h+R_t^A)}$. Further details on the implementation of the liquidity requirements are given in Appendix12.

4.1.1 Analytical Comparison of the Two Regulations

At first glance it is instructive to examine analytically how the two regulations separately and distinctively affect the insolvency and the illiquidity regions. This of course neglects all general equilibrium effects, which are however considered in the numerical solution of the next section.

Under the minimum equity requirement the run region actually expands ex ante, $(R_t^A + x_t) \leq R_t d_t + b k_t^{Min}$. This shapes bank managers' incentives to reduce leverage. Indeed the optimal leverage ratio unequivocally falls, $d_t^E = d_t - \frac{1}{R_t} z_t b k_t^{Min}$. It is the reduction in the exposure to short term funding that reduces the ex post probability of a run, which now reads as follows $\phi_t^E = \int\limits_{-h}^{R_t d_t^E - R_t^A} f(x_t) dx_t = F(R_t d_t^E - R_t^A)$. Given the expression for z_t it is easy to verify that the upper bound of the run region, $R_t d_t^E - R_t^A$, is smaller than under free capital, $R_t d_t - R_t^A$. In sum, equity requirements result in lower insolvency, since they change the incentives to leverage ex ante. This implies that they also reduce the credit extension capacity of the bank, since the overall cost of funding is larger in presence of the regulatory minimum[47]. The equity capital also reduces the illiquidity-solvency region, $x_t \in \left[R_t d_t^E - R_t^A, \frac{R_t d_t^E}{\lambda} - R_t^A\right]$, as $d_t^E < d_t$. However, the upper bound of the insolvency region falls by more than the upper bound of the illiquidity region. To sum up the main benefits of equity regulations is to reduce banks' insolvency.

Let us now examine the role of liquidity requirements. First, the ex post probability of bank run in this case is $\phi_t^m = \int_{-h}^{R_t d_t^m - m_t^R d_t^m - R_t^A} f(x_t) dx_t$. Note that in this case the liquidity buffer enters the integral, since the cash holdings are materially liquidated to cover for the deposits' withdrawals. Considering that $d_t^m < d_t$ and that m_t^R is a coefficient lower than one, the upper limit of the integral in ϕ_t^m falls. The run region shrinks ex post since cash buffers reduce the extent of the runnable liabilities. Note that the reduction in the run region also implies that managers have no need to decrease leverage compared to the competitive economy. This aspect will emerge clearly in the comparison of the simulated economies shown inin the next section. Let us now examine the impact of liquidity requirements on the illiquidity-solvency region. Given that $d_t^m < d_t$ and that $\lambda < 1$, the lower bound of the illiquidity region, $R_t d_t^m - m_t^R d_t^m - R_t^A$, falls by more than the upper bound, $\frac{R_t d_t^m - m_t^R d_t^m}{\lambda} - R_t^A$. Hence, the illiquidity-solvency region expands. Recall from the discussion done in section3.1.1 that this region represents the extent of the market threat on bank discipline. Contrary to equity requirements liquidity regulations do not affect ex ante bank managers' incentives toward reducing leverage. However, they increase the extent of the threat, even under solvency.

[47] The marginal equity returns, $\int_{R_{t+1} d_{t+1} + bk_{t+1}^{MIN} - R_{t+1}^A}^{h} \left[\frac{(R_{t+1}^A + x_{t+1}) - R_{t+1} d_{t+1}}{2}\right] f(x_{t+1}) dx_{t+1}$, fall in presence of bk_{t+1}^{MIN}, but the platform of equity holders raises. Which effects prevails also depends upon general equilibrium effects. However, the simulations below show that equity requirements generally depress investment and the economic activity compared to the liquidity requirements.

4.1.2 Quantitative Comparison of the Two Regulations

A more exact comparison of the two type of regulations requires taking into account all general equilibrium and expectational effects. This can be done through simulations. Next are shown impulse responses to productivity shocks first for an economy with equity requirements and then in one with liquidity requirements. The goal here is that of comparing the effects of actual operational prudential regimes. For this reason the requirements are modelled in each case with rules that mimic the Basel accords.

Equity requirements in the Basel accords are characterized by certain minimum levels and by a cyclical buffer, whose properties differ across Basel I, Basel II and Basel III. A rule capturing those aspects is the following:

$$bk_t^{Min} \equiv \frac{BK_t^{Min}}{Q_t K_{t+1}} = const + b_0^c \left(\frac{Y_t}{Y_{SS}}\right)^{b_1^c} \tag{28}$$

where different specifications of the parameters correspond to different regimes. In equation 28, the dependence of the minimum capital ratio on the deviation of output from its steady state is intended to mimic the cyclical sensitivity of the risk weights that affect the capital requirements under the Basel II Internal Ratings Based approach. Specifically, a negative value of b_1^c implies that the minimum capital ratio decreases with the output gap. Since the average riskiness of bank loans tends to be negatively correlated with the cycle, one can calibrate b_1^c so that equation 28 reproduces, for each value of the output gap, the capital requirement under Basel II. For $b_1^c = 0$, equation 28 reproduces the Basel I regime, in which the capital ratio is fixed [48]. Setting positive value of b_1^c reproduces a hypothetical regime along the lines of Basel III. The latter requires banks to accumulate extra capital buffers when the economy is booming[49].

[48] In fact, it has been noted that capital regulation is slightly procyclical also under Basel I, due to accounting factors.

[49] The exact calibration of the parameters in the three regimes follows Angeloni and Faia[1]. The parameters b_0^c and b_1^c are calibrated so as to ensure that the resulting required capital ratio is, at each point in the cycle, close to that resulting from the application of the actual Basel II IRB rules. The IRB risk-weighted approach requires banks to hold capital to cover unexpected losses given the distribution of potential losses. The exact methodology, based on Merton [36], implies that the capital requirement for a unit of exposure is given by (see Basel Committee on Banking

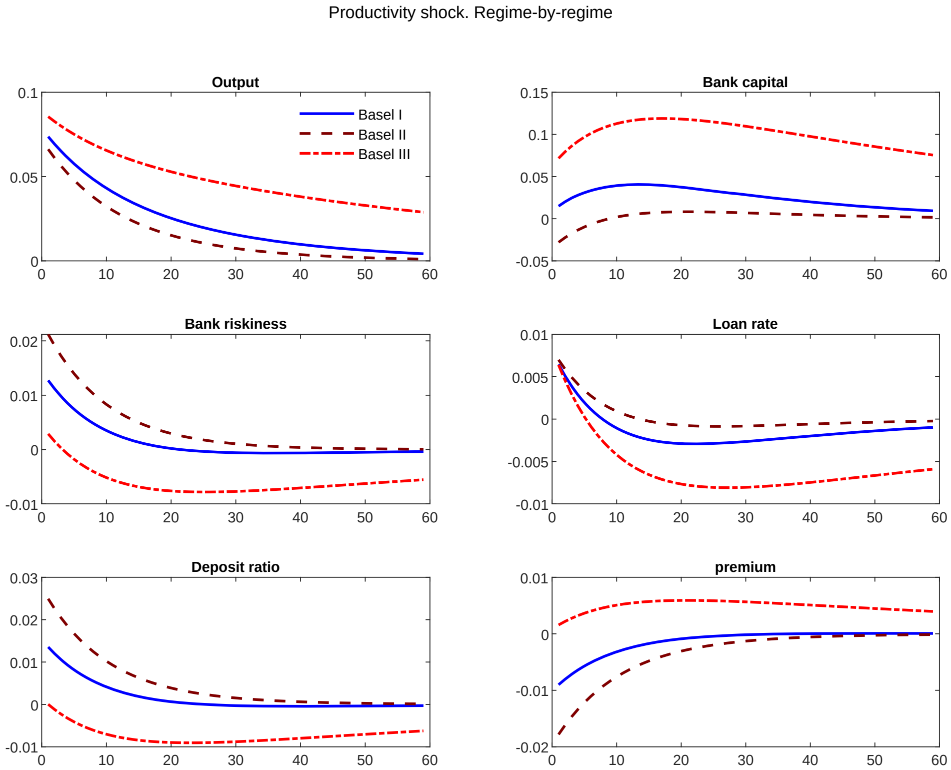

Figure 3: Impulse responses of selected variables to a productivity increase and by comparing the economy under three regulatory regimes: Basel I (solid line), Basel II (dashed line) and Basel III (dashed and dotted line).

Figure 3 below shows the responses of selected variables in the model to a one percent increase in productivity and by comparing Basel I, Basel II and Basel III regimes for equity requirements. I focus on the aggregate expansionary shock since, as already discussed above, it is sufficient to generate an increase in bank risk, which prudential authorities wish to curb.

Let us start from commenting on the comparison of the three equity requirements regimes.

Supervision [3]) $CR = LGD\left\{\Phi\left[\frac{1}{\sqrt{1-\rho}}\Phi^{-1}(PD)+\sqrt{\frac{\rho}{1-\rho}}\right]\Phi^{-1}(.999)-PD\right\}MA$where ρ is an estimate of the cross-borrower correlation and MA is an adjustment for average loan maturity. The correlation is approximated by the Basel Committee by means of the following function of PD: $\rho = 0.12\left[\frac{1-\exp(-50PD)}{1-\exp(-50)}\right]+0.24\left[1-\frac{1-\exp(-50PD)}{1-\exp(-50)}\right]$The maturity adjustment formula is given by: $MA = \frac{1+(M-2.5)b(PD)}{1-1.5b(PD)}$where M is the average maturity of loans, that we assume fixed and equal to 3 years.

Given the nature of the capital rules described above the leverage ratio remains pro-cyclical under Basel I and Basel II and becomes counter-cyclical under Basel III. The anti-cyclical behaviour of Basel III results from the anticipatory buffer motives embedded into it. Banks are requested to increase the bank capital ratio during booms, hence to reduce leverage, in anticipation of the losses in the upcoming recession. Basel III appears to be the most effective in reducing bank risk. Since this in turn reduces aggregate losses, $\Omega_t = \int_{-h}^{\widetilde{x}_t} R_t^A Q_t K_{t+1} c f(x_t) dx_t$, output tends to be higher under this regime. The transmission channel under Basel III also mimic much better the one under the Ramsey plan. Both feature a strong inter-temporal precautionary motive, that results in higher reduction of risk.

Next are shown impulse responses of an economy with liquidity requirements. Inspection of this will inform us on the difference with the transmission under equity requirements. Figure4 shows impulse responses to the usual shock and by comparing the unregulated economy with the one under liquidity requirements. As expected liquidity requirements reduces the insolvency regions by shrinking the size of the runnable liabilities. Interestingly leverage raises slightly less than in the free capital regime, but more than under any of the regulated equity regimes. This is so since liquidity requirements do not modify significantly ex ante bank managers's incentives to leverage, relatively to the free regime. Equity requirements instead do so. Another interesting aspect is that investment and credit (not shown for brevity) and output are significantly larger in the economy with liquidity requirements than in any of the economies with regulated equity ratios. The reduction in leverage induced by the equity requirements increases the overall cost of funding for the bank, which in turn scales down credit supply.

4.1.3 Welfare Comparison Across Prudential Regimes

To complete the comparison of the actual prudential regimes Table 2 shows the welfare costs of each[50]. The welfare comparison is made using as metric the fraction of household's consumption

[50] The welfare computations do not rely on first order approximations, because in an economy with time-varying distortions stochastic volatility affects both first and second moments. See for instance Schmitt-Grohe and Uribe[41].

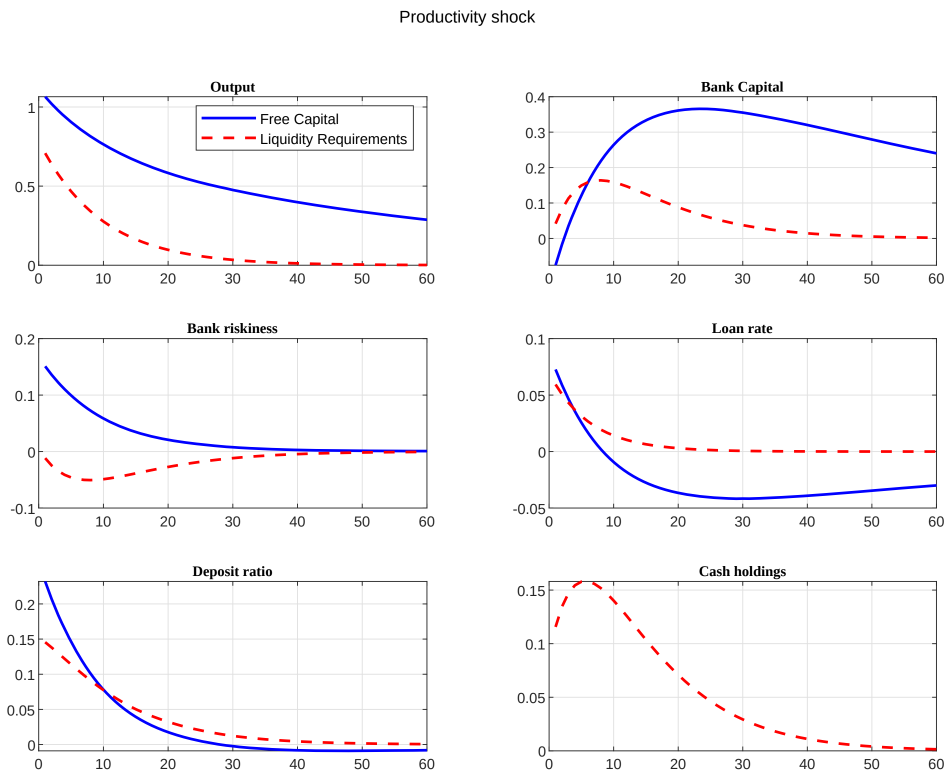

Figure 4: Impulse response functions of selected variables to a 1% increase in productivity Comparison between the unregulated economy and the economy with liquidity coverage ratios.

Table 2: **Welfare comparison across prudential regimes.**

	Welfare costs
Free Capital	0.4233
Liquidity Requirements	0
Equity Requirements, Basel I	0.0807
Equity Requirements, Basel II	0.0830
Equity Requirements, Basel III	0.0552

that would be needed to equate conditional welfare $\mathcal{W}_0$ under a generic rule to the level of welfare $\widetilde{\mathcal{W}_0}$ implied by the "best" rule. Such fraction, Υ, is defined by: $\mathcal{W}_{0,\Omega} = E_0 \left\{ \sum_{t=0}^{\infty} \beta^t U((1+\Upsilon)C_t) \right\} = \widetilde{\mathcal{W}_0}$[51]. Table 2 shows the welfare costs, Υ, associated with each regime considered and relative to the best performing. Liquidity requirements alone deliver the highest level of welfare. This is so since they are successful in reducing bank risk, but at a rather minor cost in terms of foregone credit and investment. The free capital regimes is associated with the highest welfare costs, hence is the least performing. The absence of any regulation seems to inflict high welfare costs and provides a quantification of the macroeconomic externalities. The rest of the comparison shows that equity capital regimes exhibit rather similar welfare properties.

5 Announcement Effects

Prudential regulations have shifted over the years from the Basel I to the Basel II and subsequently from the Basel II to the Basel III. The first shift took place in most countries prior to 2007, while the second shift took place after the financial crisis. Different countries announce, but introduce the regulations at different time-lags, hence resident citizens and banks might attach different probabilities to the introduction of the regulation at time t. In most countries the liquidity requirements have been announced and are being introduced gradually through a phase-in regime[52]. The na-

We focus on the *conditional* expected discounted utility of the representative agent.

[51] Simulations are done again in response to productivity and government spending shocks, two standard macro shocks.

[52] Starting from January 1, 2015 the parameter for the liquidity requirement is set to 60% of its finale value (namely 0.25 for each unit of deposits), while afterwards there are annual increments of 10% until the parameter reaches the

ture of those gradual shifts calls for examining the anticipatory effects associated to them. Upon announcements agents adjust their behaviour and the degree of adjustment depends upon the probability that they assign to the regime shift at time t. Such beliefs can change the impact of the policy change. Expectational effects can be important, and at time even induce unintended consequences, but have been mostly neglected within the literature that studied prudential regulations with static models and in absence of expectations. To measure the extent of those anticipatory effects the regulated economies are now simulated by employing Markov-switching techniques (see Farmer, Waggoner and Zha[18]) and by comparing regime shifts with agents assigning different probability to the change taking place at time t.

Figure 5 shows impulse responses of an economy subject to the usual positive productivity shock and experiencing a shift from Basel I to Basel II. This experiment is important and insightful since it took place before the 2007-2008 financial crisis. The panels in each figure plots several lines. In the dashed dotted lines the regime change does not take place, but agents attach different probabilities at time zero to the shift. The solid line instead shows what happens if the shift takes place and the economy remains in the new regime.

Several considerations emerge from the plots in Figure 5. First and foremost, an expected and actual shift to Basel II (solid line) in a booming economy induces a fall in bank capital, an increase in leverage and in bank risk, a fall in the bank lending premium and a moderation in output. With insights this experiment replicates well the patterns observed prior to the 2007, a time of Great moderation, low lending rates and high leverage. Much of the dynamic is driven by anticipatory effects. Basel II prescribes a tightening of equity requirements in recessions. If the regime is announced in an expansionary phase, agents and banks anticipate a tightening of the capital requirements once the boom decays. Hence in the future leverage will be below the level desirable in a free capital regime. Banks then optimally counteract the effect of the new regulation, by front loading an increase in short-term liabilities. This comes along with an increase in ex post

regulatory value of 100%.

probability of a run, hence of a crisis. Alongside with the build up of leverage we observe output moderation, again a response in line with pre-2007-crisis observation. As the ex post probability of a run for sure raises, so do the aggregate expected liquidation costs. This in turn reduces the increase in output.

The dashed lines show what happens if the regulator decides to maintain the Basel I regulations, while agents assign different probabilities to a regime shift at time t. This is a realistic scenario. While the shift was approved by the Basel committee at a specific date, countries entered the new regime at different dates. Hence banks in different countries have assigned different probabilities to the shift taking place at time t. Banks' tendency to increase leverage today is commensurate to the probability that they attach to the regime shift. If banks expect a change to Basel II to be more likely, they tend to leverage more to counteract the perspective undesired tightening.

Figure 6 shows the effects of a shift from Basel II to Basel III, again under an increase in productivity. The solid line shows the responses of a shift from Basel II to Basel III, similar to the one taking place after the 2007 crisis. The transmission channel is now reversed compared to the case of a shift from Basel I to Basel II. Since the economy is in a boom banks increase leverage. However, a shift to Basel III also requires them to increase equity buffers today in anticipation of the shock decay and to lower them in the future. This in turn allows banks to leverage more in the future compared to a free capital regime. Expecting higher than desired leverage in the future induces banks to contain the build-up of leverage today, the more so the higher the probability attached to the regime shift. This results in a fall in bank risk.

Figure7 below shows the transmission mechanism of the usual aggregate shock under the phased-in liquidity requirement. Each line in the panel represents the introduction of the liquidity requirements, assuming that agents expectations are progressively set as in the announced phase-in experiment.

The phase-in induces a smooth progression toward the final equilibrium. Bank risk and equity

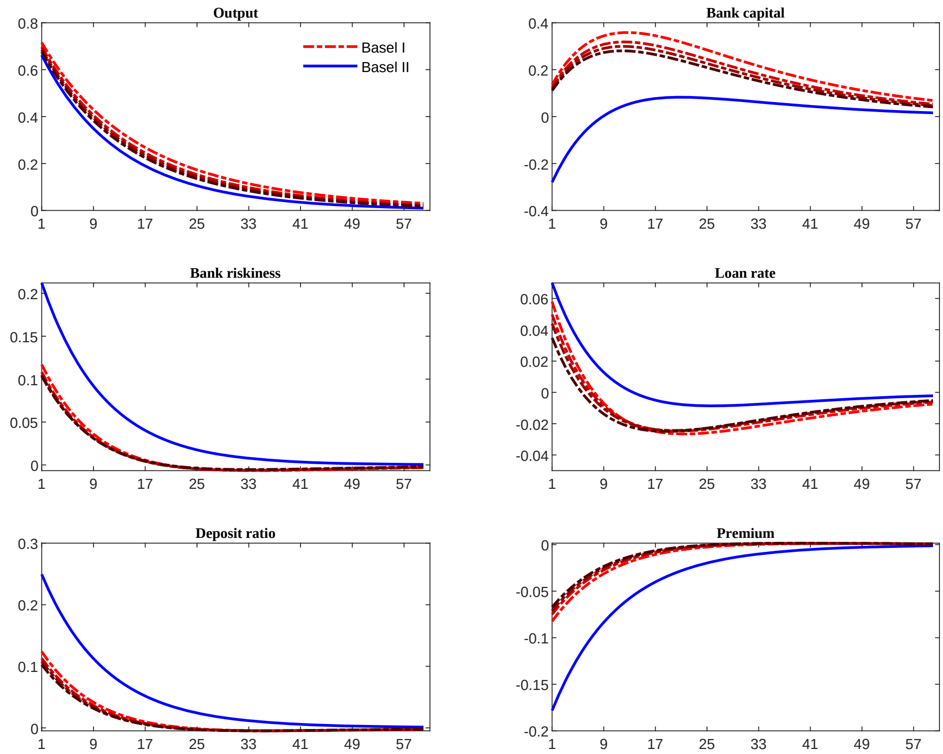

Figure 5: Impulse responses of selected variables when agents hold expectation f a regime change. Dashed lines show responses under the event that the regime shift does not take place. Solid line shows responses under the event that the regime shift takes place.

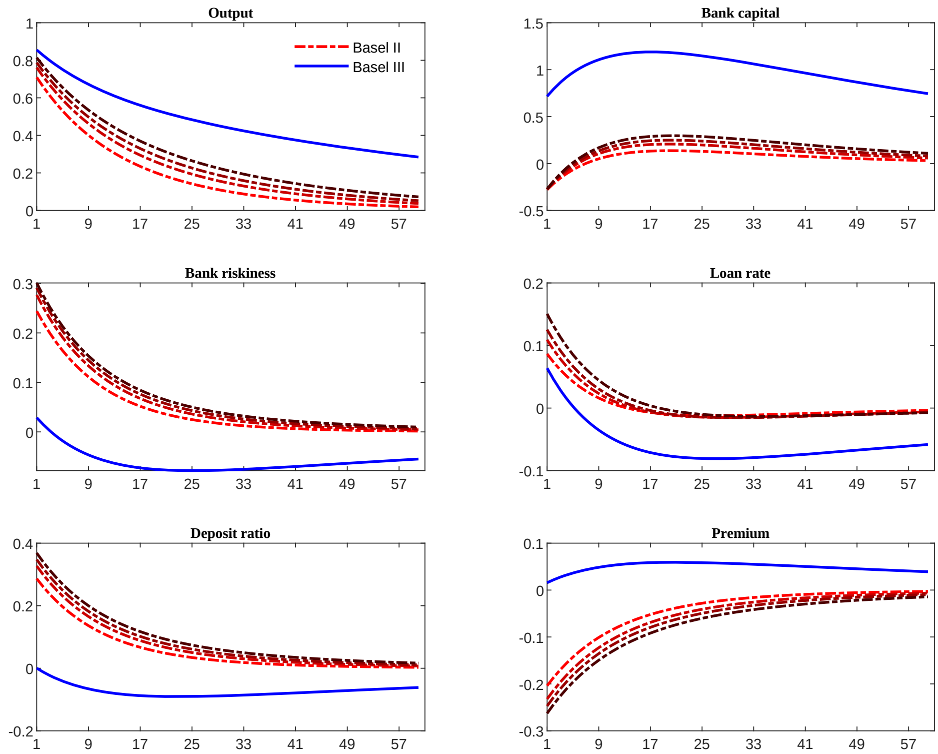

Figure 6: Impulse responses of selected variables when agents hold expectation of a regime change. Dashed lines show responses under the event that the regime shift does not take place. Solid line shows responses under the event that the regime shift takes place.

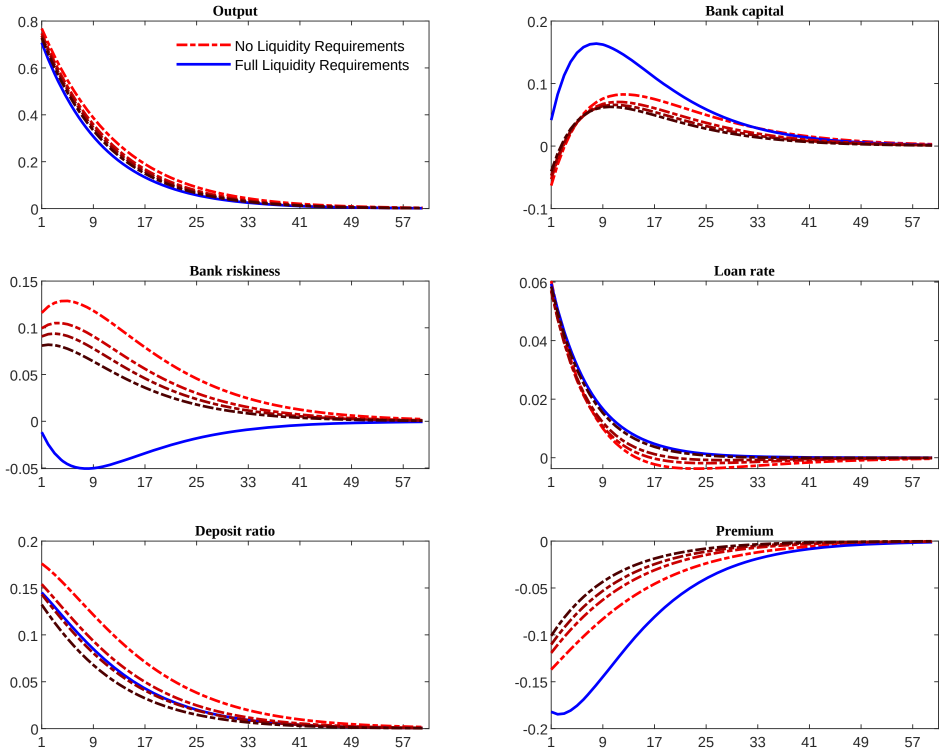

Figure 7: Impulse response to 1% increase in productivity under a phased in liquidity coverage ratio.

capital are indeed progressively reduced. The higher the probability of the regime shift at time t, the lower is the increase in leverage. The probability of a regime shift in fact measures the distance with respect to the desired level of leverage under free capital. The lower is this probability, the higher is the distance of the optimal leverage compared to the unregulated economy.

6 Conclusions

I study the optimal design of prudential regulation, both equity capital and liquidity regulation, in a macro model with information-based runs. The model delivers the endogenous build up of risk and leverage that typically emerges prior to debt-crises. Bank runs are privately efficient as they allow the club of outside financiers to discipline the bank manager, who re-deploys projects and choose the optimal funding structure on their behalf. Despite this however, aggregate externalities emerge, both technological and pecuniary ones. This provide a rationale for prudential regulation. A Ramsey planner, designing capital regulations, optimally sets higher average values for equities and requires counter-cyclical buffer, with similar cyclical properties to Basel III. The reason is twofold. First, the planner internalizes the pecuniary externalities that are instead neglected by bank managers. Second, by acting under commitment the planner has stronger precautionary saving motives.

The rationale for two distinct prudential regulations, equity capital and liquidity, is grounded in the distinction between insolvency and illiquidity-solvency. Equity capital, by reducing the extent of leverage ex ante, reduce the insolvency region or the region of run for sure. Liquidity requirements provide buffer liquidity that reduce the extent of runnable liabilities, hence they reduce the probability that a solvent bank might turn illiquid.

At last, to fully exploit the macro implications of prudential regulation I assess the role of announcements on banks' anticipatory behaviour. Announcing a shift to Basel II during an expansionary phase implies that agents and banks anticipate a tightening of the capital requirements once the boom decays. To undo the consequences of a less than desirable level of leverage, banks increase that at the time of the announcement. This in turn raises the probability of a run in the future. The example is instructive on the potential unintended consequences of policies announced by regulators who fail to take into account anticipatory effects.

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7 Appendix A. Expected Loss on Risky Deposits

When the probability of bank run is non-zero, the expected payoff on deposits, taking into account the risk of run, is below the riskless return R. The computation below holds for any period t. Consider the payoff of deposits per unit of funds intermediated by the bank in two events: run for sure and no run (all other cases). In the first case the payoff is $[1-\xi(1-\lambda)](1-c)(R_t^A+x_t)$. This holds in the interval of x_t comprised between $[-h;(R_t d_t - R_t^A)]$. The expected value of this payoff is $\int_{-h}^{\widetilde{x_t}} [1-\xi(1-\lambda)](1-c)(R_t^A+x_t)f(x_t)dx_t$. This can be written, solving the integral and using the expression for the probability of run $\phi_t = \int_{-h}^{\widetilde{x_t}} f(x_t)dx_t = F(\widetilde{x_t}) = F(R_t^A - R_t d_t)$, as:

$$
\begin{aligned}
[1-\xi(1-\lambda)](1-c)\int_{-h}^{\widetilde{x_t}}(R_t^A+x_t)f(x_t)dx_t &= \\
&= [1-\xi(1-\lambda)](1-c)\left[\phi_t R_t^A+\phi_t\right] \\
&= \phi_t [1-\xi(1-\lambda)](1-c)\left[R_t^A+1\right]
\end{aligned}
\tag{29}
$$

In the range of x_t in which the run does not occur, the payoff is equal to $R_t d_t$. Its expected value is obtained by multiplying it by the probability of the respective event, $(1-\phi_t)$. Overall, the expected payoff on deposits per unit of intermediated funds therefore is given by:

$$
\phi_t [1-\xi(1-\lambda)](1-c)\left[R_t^A+1\right] + (1-\phi_t)R_t d_t \tag{30}
$$

The expected loss on deposits, relative to the no-run state, per unit of intermediated funds, is obtained by subtracting the above expression from $R_t d_t$, the contractual payoff

$$
R_t d_t - \phi_t [1-\xi(1-\lambda)](1-c)\left[R_t^A+1\right] - (1-\phi_t)R_t d_t \tag{31}
$$

The expected return on deposits (payoff per unit of deposits), corrected for risk, is $R_t(1-\phi_t g_t)$, where $g_t = R_t + [1-\xi(1-\lambda)](1-c)\left[R_t^A+1\right]$.

8 Appendix B. Good and Capital Production Sectors

The goods production sector operates under full competition an homogenous of degree 1 technology $Y_t = F(N_t^1, K_t)$, where N_t^1 is labour demand from the production sector. Accordingly the marginal productivity of capital and labour in every period t are given by $MPN_t = \frac{\partial F(N_t^{1,h}, K_t)}{\partial N_t^{1,h}}, MPK_t = \frac{\partial F(N_t^{1,h}, K_t)}{\partial K_t}$. In every period firms producing goods can rent capital from capital producers. In equilibrium the rental rate, Z_t, will be equal to the marginal productivity of capital: $Z_t = MPK_t$. Banks invest directly in capital projects, whose aggregate evolution reads as follows:

$$K_{t+1} = (1-\delta)K_t + I_t - \Phi\left(\frac{I_t}{K_t}\right)K_t \tag{32}$$

where I_t is aggregate investment. The cost function $\Phi(\cdot)$ is convex and satisfies $\Phi(\delta) = 0$ and $\Phi^{'}(\delta) = 0$, where δ is the depreciation rate of capital. The reason for introducing the Tobin's adjustment costs is to obtain variable price of capital which help to capture dynamic valuation or balance-sheet channel. Physical capital is produced by a capital producer sector that chooses investment and the capital stock by maximizing the sum of future discounted revenues, $Z_{t+1}K_{t+1}$, subject to (32). Capital producers discount future profits by the return that they have to pay on bank funds, R_t^A. The first order conditions, with respect to $\frac{I_t}{K_t}$ and K_{t+1}, deliver following equilibrium price of capital:

$$Q_t = \left[\Phi^{'}(\frac{I_t}{K_t})\right]^{-1} \tag{33}$$

and the following gross return from holding one unit of capital between t and $t+1$:

$$R_t^A \equiv \frac{Z_{t+1} + Q_{t+1}((1-\delta) - \Phi\prime(\frac{I_{t+1}}{K_{t+1}})\frac{I_{t+1}}{K_{t+1}} + \Phi(\frac{I_{t+1}}{K_{t+1}}))}{Q_t} \tag{34}$$

9 Appendix C. Proposition 1

The optimal deposit ratio is obtained by studying the shape of the surplus function for different shock intervals. The derivations also show that at the optimal deposit ratio falls in an interval whereby a unique threshold divides the region of run and of no run. For convenience I report the surplus function here:

$$\mathcal{S}=\left\{\begin{array}{c}\int\limits_{-h}^{\widetilde{x}_t}\left[1-\xi(1-\lambda)\right](1-c)(R_t^A+x_t)f(x_t)dx_t+\int\limits_{\widetilde{x}_t}^{\hat{x}_t}\left[(1-\xi)(R_t^A+x_t)+\xi R_t d_t\right]f(x_t)dx_t+\\ +\int\limits_{\hat{x}_t}^{h}\left\{(1-\xi(1-\lambda))(R_t^A+x_t)\right\}f(x_t)dx_t\end{array}\right\} \tag{35}$$

- Region A or *super-solvency* region: $R_t d_t < \lambda(R_t^A - h)$. In this case a run can never take place since if all depositors run the demanded liquidity is smaller than the asset return under the lowest possible realization of the shocks. In this case the surplus reduces to $\int\limits_{-h}^{h}\left\{(1-\xi(1-\lambda))(R_t^A+x_t)\right\}f(x_t)dx_t$. This integral is independent of d_t, hence the function is flat.

- Interval B: $\lambda(R_t^A - h) < R_t d_t < R_t^A - h$. In this case the depositors would run if they have to liquidate by themselves, but they would not if the bank manager liquidates the projects on their behalf. This implies that the surplus function include only the second and the third term of the full surplus function, 35, hence it reads as follows:

$$\mathcal{S} = \int\limits_{-h}^{\hat{x}_t}\left[(1-\xi)(R_t^A+x_t)+\xi R_t d_t\right]f(x_t)dx_t \tag{36}$$

$$+\int\limits_{\hat{x}_t}^{h}\left\{(1-\xi(1-\lambda))(R_t^A+x_t)\right\}f(x_t)dx_t \tag{37}$$

The first derivative of the above function is $\frac{R_t^2 d_t}{\lambda}f(\hat{x}_t)+\xi R_t F(\hat{x}_t)-\frac{R_t^2 d_t(1-\xi(1-\lambda))f(\hat{x}_t)}{\lambda}>0$. To see this we can compute it under a uniform distribution $f(x_t)=\frac{1}{2h}$ and fixing $\xi=\frac{1}{2}$. In this case the derivative becomes $\frac{R_t}{4h}\left[\frac{R_t}{\lambda}d_t-(R_t^A-h)\right]$, which is positive for all admissible parameter values. Hence in this interval the function is upward sloping and convex.

- Interval C: $R_t^A - h < R_t d_t < \lambda(R_t^A + h)$. The function is equal to:

$$\int_{-h}^{\widetilde{x}_t} \left[1 - \xi(1-\lambda)\right](1-c)(R_t^A + x_t) f(x_t) dx_t + \tag{38}$$
$$+\int_{\widetilde{x}_t}^{\hat{x}_t} \left[(1-\xi)(R_t^A + x_t) + \xi R_t d_t\right] f(x_t) dx_t +$$
$$+\int_{\hat{x}_t}^{h} \left\{(1-\xi(1-\lambda))(R_t^A + x_t)\right\} f(x_t) dx_t$$

Using Leibniz rule, the first derivative is $\xi R_t \left[F(\hat{x}_t) - F(\widetilde{x}_t)\right] - \xi\lambda c R_t d_t f(\widetilde{x}_t)$. Once again under the uniform distribution and the $\xi = \frac{1}{2}$ this derivative becomes, $\frac{R_t^2 d_t}{4h}\left[\frac{(\lambda-1)^2}{\lambda} - c(\lambda+1)\right]$. The condition is satisfied if c is zero, or else if λ and c are sufficiently low.

- Interval D: $\lambda(R_t^A + h) < R_t d_t < R_t^A + h$. In this interval the return to outsiders reduces to:

$$\int_{-h}^{\widetilde{x}_t} \left[1 - \xi(1-\lambda)\right](1-c)(R_t^A + x_t) f(x_t) dx_t + \tag{39}$$
$$+\int_{\widetilde{x}_t}^{h} \left[(1-\xi)(R_t^A + x_t) + \xi R_t d_t\right] f(x_t) dx_t$$

Define for convenience

$\Theta_t = \left[1 - \xi(1-\lambda)\right](1-c)(R_t^A + x_t) f(x_t)$ and $\Gamma(d_t) = \left[(1-\xi)(R_t^A + x_t) + \xi R_t d_t)\right] f(x_t)$. Applying the Leibniz rule the first order condition reads as follows: respect to d_t reads as follows:

$$\frac{\partial \widetilde{x}_t}{\partial d_t}\Theta_t \mid_{\widetilde{x}_t} - \frac{\partial \widetilde{x}_t}{\partial d_t}\Gamma(d_t) \mid_{\widetilde{x}_t} + \int_{\widetilde{x}_t}^{h} \frac{\partial \Gamma(d_t)}{\partial d_t} f(x_t) dx_t = 0 \tag{40}$$

which, upon substituting derivatives and recalling that $R_t d_t = (R_t^A + \widetilde{x}_t)$, the first order condition becomes:

$$\left[(1-\xi(1-\lambda))(1-c)R_t d_t f(\widetilde{x}_t)\right] R_t - \left[R_t d_t f(\widetilde{x}_t)\right] R_t + \xi R_t \left[1 - F(\widetilde{x}_t)\right] = 0 \tag{41}$$

Intuitively, a marginal increase in the deposit ratio has three effects. First, it increases the range of x_t where a run occurs, by raising the upper limit of the first integral; this effect increases the overall return to outsiders by $[(1-\xi(1-\lambda))(1-c)R_t d_t]\,R_t$. Second, it decreases the range of x_t where a run does not occur, by raising the lower limit of the second integral. The effect of this on the return to outsiders is negative and equal to $\xi\,[R_t d_t]\,R_t$. Third, it increases the return to outsiders for each value of x_t where a run does not occurs; this effect is $\left(\int_{\widetilde{x}_t}^{h} \xi R_t f(x_t) dx_t\right) = \xi R_t \left[1 - F(\widetilde{x}_t)\right]$. The optimal deposit ratio reads as:

$$d_t^* = \frac{1}{R_t} \frac{\xi(1-F(\widetilde{x}_t))}{\left[\xi(\lambda-1)(1-c)-1\right] f(\widetilde{x}_t)} \tag{42}$$

It can be easily shown that under a uniform distribution, with density function $f(x) = \frac{1}{2h}$, and under a bargaining power of $\xi = \frac{1}{2}$, the optimal deposit ratio reads as follows:

$$d_t^* = \frac{1}{R_t} \frac{R_t^A + h}{2 - \lambda + c(1+\lambda)} \tag{43}$$

- Interval E: $R_t^A + h < R_t d_t$. The function reduces to $\int_{-h}^{h} \left[1-\xi(1-\lambda)\right](1-c)(R_t^A + x_t) f(x_t) dx_t$. This is independent of d_t, hence the function is flat. *Q.E.D.*

10 Appendix D. Data Appendix

Macro Data for the Eurozone are from Eurostat, employment data from OECD. Deposit and loan rates (household deposit rates and loan rates for the non-financial corporations sector) are from the ECB Statistical Data Warehouse.

For the US, data on macro variables and interest rates are from Federal Reserve Bank of St. Luis. Deposit rates are average rates of deposits in M2, lending rates are mortgage rates. Employment data is also from OECD.

For both, the Euro Area and the US, bank risk is approximated by the realized volatility of the total return Datastream indices for banks. The realized volatility is calculated as the average daily absolute returns of the Datastream total return bank indices for the Euro Area and the US, respectively, over each quarter.

All data were detrended using a Hodrick Prescott filter with a smoothing factor of 1600. Estimation samples vary according to data availability.

11 Appendix E. Bank Capital Accumulation and Bank Risk with Minimum Requirements

The probability of run in this case is given by $\phi_t^E = \int\limits_{-h}^{R_t d_t^E - R_t^A} f(x_t)dx_t$.Since d_t^E is smaller than d_t, it follows that in this case the probability of a run is also smaller. Note that in the run region I am not including the minimum bank capital. The reason is that, while its presence reduces the ex ante incentives of the bank manager to leverage, ex post equity capital cannot be liquidated instantaneously in the event of runs. Finally, the bank capital accumulation equation needs to be modified too. Solving **??** for the return of the capitalist and substituting in the accumulation equation one gets:

$$BK_{t+1} = \theta \left\{ \left[\int\limits_{R_t d_t + bk_t^{Min} - R_t^A}^{h} \left\{ (1 - \xi(1-\lambda)) \left[(R_t^A + x_t) - R_t d_t \right] \right\} f(x_t)dx_t \right] Q_t K_{t+1} \right\} \tag{44}$$

which reduces to the bank capital accumulation under free capital, for $bk_t^{Min} = 0$.

12 Appendix F. Liquidity Requirements

Under liquidity requirements the probability of a run is given by $\phi_t^m = \int\limits_{-h}^{R_t d_t^m - m_t^R d_t^m - R_t^A} f(x_t)dx_t$. Note that contrary to the case of equity requirement, for this case I maintain the cash holding ratio into the run probability. The reason being that cash holdings can be immediately used to reduce the extent of the runnable liabilities.

Expected returns accruing to the bankers read as follows:

$$R_t^b = \int\limits_{R_t d_t^m - m_t^R d_t^m - R_t^A}^{h} \left\{(1-\xi(1-\lambda))\left[(R_t^A + x_t) - R_t d_t\right]\right\} f(x_t) dx_t \tag{45}$$

Given this the bank capital accumulation, which is mainly done of retained earnings, reads as follows:

$$BK_{t+1}^m = \theta[\left[\int\limits_{R_t d_t^m - m_t^R d_t^m - R_t^A}^{h} \left\{(1-\xi(1-\lambda))\left[(R_t^A + x_t) - R_t d_t\right]\right\} f(x_t) dx_t\right] Q_t K_{t+1}] \tag{46}$$