

# Financial Risk Capacity <sup>\*</sup>

## Job Market Paper

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### Abstract

Financial crises appear to persist if banks fail to be recapitalized quickly after large losses. I explain this impediment through a model where banks provide intermediation services in asset markets with informational asymmetries. Intermediation is risky because banks take positions over assets under disadvantageous information. Large losses reduce bank net worth and, therefore, the capacity to bear further losses. Losing this capacity leads to reductions in intermediation volumes that exacerbate adverse selection. Adverse selection, in turn, lowers bank profits which explains the failure to attract new equity. These financial crises are characterized by a depression in economic growth that is overcome only as banks slowly strengthen by retaining earnings. The model is calibrated and used to analyze several policy interventions.

JEL: E32, G01, G21

Key Words: Financial Crisis, Adverse Selection, Capacity Constraints, Capital Requirements

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# 1 Introduction

Oftentimes financial crises originate from episodes of extreme bank losses. Declines in economic activity follow when banks retract lending after their equity is lost. This suggests that the impact and duration of crises could be mitigated if equity were quickly injected into the financial industry. Not surprisingly, the slow recovery of bank equity was a major concern for policy makers, academics, and practitioners during the financial crisis of 2008-2009. In fact, during his only television interview, the Chairman of the Federal Reserve, Ben Bernanke, was asked when he would consider the crisis to be over. He answered, “When banks start raising capital on their own.”<sup>1</sup> Why is it then that banks cannot attract capital in times of crises?

This paper approaches this question from a novel angle. I adopt the view that banks are intermediaries in financial markets that feature asymmetric information.<sup>2</sup> Indeed, by dealing with a large number of parties, banks can dilute the risk of transacting under asymmetric information. However, in reality, banks cannot dilute risk entirely because financial intermediation is risky. I also follow the literature on financial frictions in that the capacity to tolerate financial intermediation risk, *i.e.* the *financial risk capacity*, is tied to bank net worth. Consequently, lending conditions depend on the evolution of this variable. These features imply that large reductions in bank net worth magnify financial crises because they exacerbate adverse selection. The intuition is that when banks run out of net worth, they must cut back on loans per unit of collateral to decrease their exposure to future losses. In turn, borrowers respond using assets of lower quality as collateral, something that depresses lending even more. Ultimately, this form of adverse selection can reduce bank profitability, and without profitable opportunities the financial system cannot attract new equity. This paper shows that this transmission mechanism operates even when the information structure and the production possibility of the economy are constant.

Asymmetric information is key for this result. Absent other frictions, competition arguments suggest that banks should easily attract new equity in times when the economy most needs it. After all, like with any other product, marginal profits from intermediation should be higher when supply is lower. Thus, to deliver substantial real effects, a theory that links financial intermediation to bank net worth must explain why banks are not quickly recapitalized after large losses. This paper shows that asymmetric information breaks this equilibrium force. Asymmetric information can lead to reductions in returns on equity (ROE) that preclude banks from being recapitalized despite that financial resources are readily available. This distinguishes from other macroeconomic models that study financial intermediation.<sup>3</sup> In these models, banks cannot raise equity because bankers are fully-invested specialists and/or face other agency costs. However, these models deliver increases in bank ROE after bank losses, an opposite but testable implication. Moreover, in my model, the economy responds very differently to bank losses of different magnitude. The paper shows that equity injections are effective stabilizers of financial crises for moderate financial losses but fail to occur after large losses. This feature has important consequences for policy interventions as I argue later.

I formalize this insight through a model that has four ingredients. (1) There is a need to trade capital goods. (2) Financial intermediation facilitates trade because there is asymmetric information in capital markets. (3) Net worth evolves through time because intermediation is risky. (4) Net worth is essential

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<sup>1</sup>This quote was taken from the interview titled the “[The Chairman](#)”, 60 Minutes, CBS News, March 15, 2009. Similarly, the slow recovery of intermediary capital is the subject of Darrell Duffie’s 2010 Presidential Address to the American Finance Association (see [Duffie, 2010](#)).

<sup>2</sup>This is a common view in banking theory (see [Freixas and Rochet, 2008](#)). [Boyd and Prescott \(1986\)](#) provide a formal model where banks play this role. Another example is [Gorton \(2010\)](#) arguing, “The essential function of banking is to create a special kind of debt, debt that is immune to adverse selection by privately informed agents.”

<sup>3</sup>See the following section for a more detailed discussion about these models.

to provide intermediation because banks face limited-liability constraints. Together, these four ingredients deliver recurrent and persistent financial crises. These crises are characterized by contractions in volumes of intermediation and reductions in collateral quality that lead to economic declines. In parallel, banks expect low equity returns, which is why they fail to attract equity injections.

I model the banking system as a competitive sector that provides intermediation services for the reallocation of capital between agents in two sectors of the economy. As in [Kiyotaki and Moore \(2008\)](#), the first sector comprises producers of capital goods in need of funds. The second sector comprises agents that lack investment projects but, in contrast, have the resources to carry them out. The fundamental economic problem is that funds must flow from the latter to the former group, and capital must flow in the opposite way. The friction that prevents the direct flow of resources is that capital producers have private information about the quality of capital units used in these transactions. Banks ameliorate this problem. They offer risk-free deposits to obtain funds from consumption producers. They transfer these funds to capital producers and take positions over a part their capital units (under asymmetric information). By facilitating trade, financial intermediation is fundamental for economic growth.

When parties share common information, the environment collapses to a classic stochastic-growth economy. These economies fluctuate only in response to shocks that affect the production possibility. Moreover, there is no need for financial intermediation. With asymmetric information about the quality of capital, banks dilute the idiosyncratic risk of transacting under disadvantageous information. However, if the distribution of capital quality is known, despite asymmetric information, banking is not risky. In equilibrium, banks can infer which qualities of capital are traded and, therefore, the value of their asset positions is risk-free.<sup>4</sup> Without this additional source of risk, business cycles can originate from shocks that disperse the quality capital as in, for example, [Bigio \(2011\)](#) or [Kurlat \(2011\)](#). These shocks do not affect the production possibility but have real effects by aggravating adverse selection. However, fluctuations in these models are unrelated to the condition of banks. Furthermore, in these economies, severe adverse selection persists only if shocks are persistent.

This theory needs two additional ingredients to associate financial crises to low bank net worth. First, net worth must fluctuate. Second, net worth must matter. In the model, profits from intermediation are risky because, in addition to asymmetric information, the capital-quality distribution is, *a priori*, uncertain. In equilibrium, banks hold positions in the lower tail of the capital-quality distribution. Since this distribution evolves through time, the value of the banks' asset positions is risky. This induces fluctuations in bank net worth.<sup>5</sup>

To induce a role for net worth, I assume banks face limited-liability constraints. Under limited liability, banks must resort to their internal funds to finance any possible operational loss. This constraint makes bank net worth a key state variable: with lower net worth banks must downsize their assets and liabilities to guarantee solvency upon future contingencies. Eventually, this reaction is responsible for the feedback-loop between asymmetric information and the evolution of net worth. Furthermore, this aspect also induces an externality: banks can fail to internalize that larger positions today may lead to greater losses tomorrow that,

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<sup>4</sup>Formally, this presumes banks can exploit the law of large numbers to wipe out financial risk: the conditional expected quality of assets bought at a given price converges to the average quality bought. Without risk, competition drives profits to 0 and bank equity plays no role. Formal arguments appear in [Glosten and Milgrom \(1985\)](#).

<sup>5</sup>Changes in the distribution of firm revenues have been found to precede recessions (see [Bloom \(2009\)](#) and [Bloom et al. \(2009\)](#) for documentation). Assuming the distribution is uncertain is a convenient, yet realistic, way of introduce risk into intermediation under asymmetric information. Very recently, a number of studies have provide several theories to explain the effects of changes in the distribution of idiosyncratic shocks to production units (see examples, [Arellano et al. \(2010\)](#), [Gilchrist et al. \(2010\)](#) or [Schaal \(2011\)](#)). I relate these changes to the ones in my model because capital of different qualities can be thought of as different productive units.

in the aggregate, affect the quality of assets traded. This is particularly damaging if adverse selection prevents banks from raising equity, and consequently, prolongs downturns.

To summarize the mechanics of the model, consider the following hypothetical simulation. Suppose there is a sequence of shocks to the distribution of capital quality that lead to systematic financial losses. Losses are financed by liquidating a substantial portion of a bank's net worth. Thus, net worth is depleted making it impossible to sustain the same magnitude of losses in the future. Banks respond by scaling down their operations and thereby exacerbating adverse selection. Adverse selection decreases expected bank profits and precludes external recapitalizations. Instead, the financial system is recapitalized only through retained earnings. Yet, this process must be very slow since volumes of intermediation and marginal profits are already low. Surprisingly, to have real effects, these shocks do not need to affect the production possibility or the information structure of the economy.

Figure 1 suggests how similar mechanics could have operated during the 2008-2009 financial crisis. The top-left panel plots the evolution of tangible net worth for a group of selected U.S. bank holding companies (with and without TARP injections) during the last decade. The figure shows that, excluding TARP, this variable deviated from trend in the quarters prior to the Great Recession (second gray shaded area). The bottom-left panel describes the decline in the nominal stock of capital, a symptom of the deceleration in economic activity. The top-right panel shows that returns on equity (ROE) were stable during the period prior to the crisis. However, bank ROE falls during the recession and remains persistently below its historical average since. The bottom-right panel presents bank dividends and equity injections. Issuances were high in comparison to historical records but far from replenishing private bank equity.<sup>6</sup>

I tackle several technical and empirical challenges to solve and calibrate the model. The model features asymmetric information, limited-liability constraints, and aggregate shocks. Despite this, it is highly tractable. I also develop an algorithm that allows studying its global behavior. On the empirical side, I construct a set of aggregate banking time series that correct institutional changes and isolate TARP injections.<sup>7</sup> I calibrate the model and provide rough measures of the effects of dividend taxes and capital requirements. These policy exercises show that the frequency and duration of financial crises can be reduced at the expense of economic growth in normal times.

The rest of the paper is organized in the following manner. The next section relates the paper to the literature. Section 2 introduces the model. Section 3 provides a commercial-banking interpretation of the model. Section 4 characterizes equilibria. Section 5 presents two analytic examples to underscore the role of asymmetric information in this economy. Section 6 describes the empirical strategy used to reconstruct banking measures and presents the results from the quantitative exercises. Section 7 describes the effects of several policy experiments. Section 8 discusses some extensions, and Section 9 concludes. The computational algorithm, proofs, and data definitions are relegated to the appendix.

## 1.1 Relationship with the literature

? Christiano et al. (2009)

**Financial intermediation in macroeconomics.** As portrayed in Figure 1, the net worth of the banking system seems to have been a driving factor during the Great Recession. The literature explains the relevance of

<sup>6</sup>The figure reports reconstructed time series of banking indicators based on the empirical strategy described in Section 6.

<sup>7</sup>Since the beginning of the crisis, many non-bank institutions effectively became Bank Holding Companies. For example, the bank equity time series reported by Flow of Funds has substantial increments after Goldman Sachs converts into a Bank Holding Company.

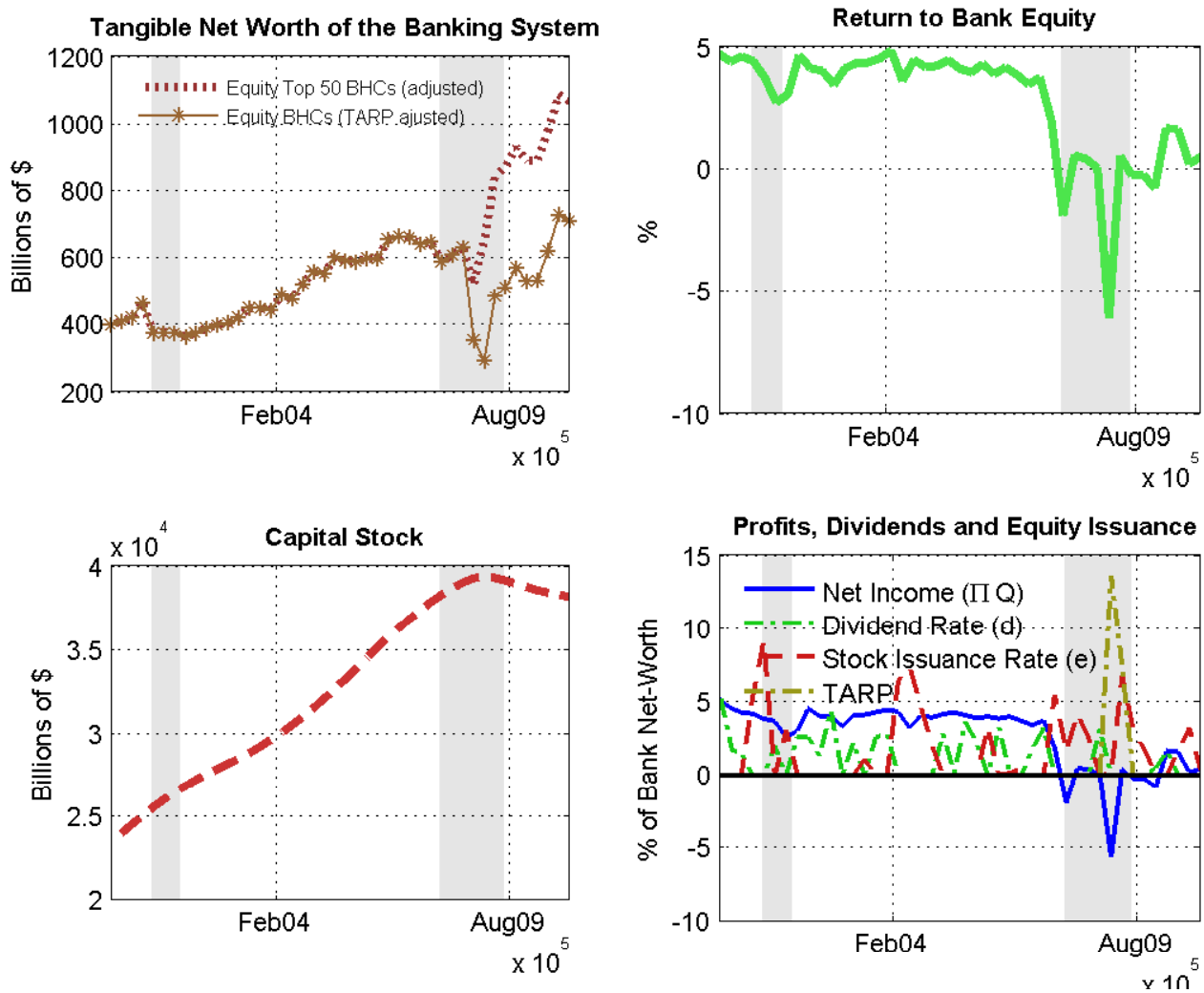


Figure 1: U.S. Banking Indicators and Capital Accumulation.

this variable for the efficient allocation of resources from several perspectives. This paper is closely related to theories in which the financial system's net worth reduces agency costs (or leverage constraints) that constrain financial intermediation.<sup>8</sup> Agency costs faced by entrepreneurs were incorporated into business cycle models in the now classic financial accelerator of models of [Bernanke and Gertler \(1989\)](#) and [Bernanke et al. \(1996\)](#). [Holmstrom and Tirole \(1997\)](#) were among the first to incorporate similar frictions into a financial sector. In their framework, the financial sector's net worth reduces agency costs because bankers have more incentives to increase the return on loans when they have more skin in the game. With more net worth, banks can provide more intermediation. Several recent studies have introduced a financial sector with similar characteristics into quantitative business cycle models to quantify various financial stabilization policies. For example, [Gertler and Karadi \(2011\)](#) or [Gertler and Kiyotaki \(2010\)](#) study the benefits of government injections targeted to recapitalize FIs. [Martinez-Miera and Suarez \(2011\)](#) incorporate a similar feature into a macro model where

<sup>8</sup>Following [Diamond and Dybvig \(1983\)](#), another stream of research has emphasized the role of the financial sector's net worth in bank runs caused by maturity mismatches. In these models, financial crises arise when an exogenous shock to the demand and supply of short run funds affects financial institutions. This literature underscores that the availability of funds (for the whole financial system) determines the effectiveness of internal insurance mechanisms against idiosyncratic shocks. From this perspective, the financial system's net asset position matters because it can preclude bank runs. Other seminal contributions in this area include [Holmstrom and Tirole \(1998\)](#) or [Allen and Gale \(1998\)](#). [Bolton et al. \(2010\)](#) relate this literature with asymmetric information. See [Sargent \(2011\)](#) for a recent survey.

bank net worth affects the risk structure across loans. Their model is used to study capital requirements. I perform similar policy exercises here also.<sup>9</sup>

This paper is closer to the work of [Brunnermeier and Sannikov \(2011\)](#) and [He and Krishnamurthy \(2009\)](#) because intermediary losses have an additional propagation mechanism. However, propagation in those papers occurs because financial shocks are amplified by fire-sale spirals. Fire sales occur when banks must meet obligations by liquidating capital whose price may fall rapidly if large quantities are liquidated simultaneously.<sup>10, 11</sup>

In common with the literature, bank net worth is key to allocating resources efficiently in this model. However, the novelty here is that financial risk is exacerbated by asymmetric information. Besides this propagation mechanism, the main distinction is in the incentives to recapitalize banks during a crises. In the literature, agency costs increase as net worth is lost. This means that the value of an additional unit of bank equity is greater in times of crises. If in those models inside equity injections were possible, one could expect rapid recapitalizations in times of crises.<sup>12</sup> This distinction is relevant because financial shocks have a mitigated impact if they are counterbalanced by equity injections. Here, in contrast, adverse selection reduces the profitability of equity injections. As a consequence, bankers choose not to do so, though it is always possible to inject equity.

Another common explanation to the slow recapitalization of banks is the debt overhang problem stressed by [Myers \(1977\)](#). Debt overhang occurs when banks are unable to raise new equity because future returns will go to current debt holders. [Philippon \(2010\)](#) and [Philippon and Schnabl \(2011\)](#) apply this corporate finance insight to the banking industry and study government policies.

The constraints on intermediation caused by low-net worth produce an externality. In that dimension, the model is also similar to [Lorenzoni \(2008\)](#). That paper combines features of the bank run literature with limited commitment on the side of bankers. That paper identifies a fire-sale externality that stems from excessive risky intermediation (relative to a social optimal). The externality here stems from bankers not internalizing that by leveraging excessively. They may run out of capital and cause severe adverse-selection in the future.

**Asymmetric information in macroeconomics.** Beginning with the seminal ideas of [Stiglitz and Weiss \(1981\)](#) and [Myers and Majluf \(1984\)](#), we know that asymmetric information in financial markets can cause credit rationing phenomena that affect economic performance. My paper also follows a recent line of these ideas into general-equilibrium. [Carlstrom and Fuerst \(1997\)](#) use private information in the return to investment to explain credit rationing during the cycle.<sup>13</sup> [Eisfeldt \(2004\)](#) studies a model where, like here, the quality of existing assets is private information. In this environment, assets are sold under asymmetric information for risk-insurance motives. Eisfeldt's argument shows how asymmetric information limits risk insurance. [Bigio \(2011\)](#) and [Kurlat \(2011\)](#) study models in which assets are sold under asymmetric information

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<sup>9</sup>In a similar environment, [Rampini and Viswanathan \(2011\)](#) study the effects of bank losses on investment and financing premia. In their model intermediary capital matters because a larger portion of a firm's capital can be collateralized if loans are intermediated rather than lent directly.

<sup>10</sup>Similar feedback between losses in intermediary capital and reductions in the value of entrepreneurial capital occur in models such as [Gromb and Vayanos \(2002\)](#) and [Brunnermeier and Pedersen \(2009\)](#). [Vayanos and Wang \(2011\)](#) introduce asymmetric information into this framework

<sup>11</sup>Fire sales were first explained by [Shleifer and Vishny \(1992\)](#). [Diamond and Rajan \(2011\)](#) study strategic behavior by banks to exploit fire sales by their competitors.

<sup>12</sup>This channel is shut down when intermediaries are fully invested in their banks. When intermediaries are specialists without additional sources of fresh capital wealth, there are no additional sources from which to replenish bank equity.

<sup>13</sup>[Martin \(2009\)](#) compares pooling with separating equilibria in a similar context in which the quantity of collateral interest rates are used as screening devices.



with the objective of relaxing financial constraints. These papers explain how shocks that exacerbate adverse selection can generate recessions. Other models that study lemons markets, such as [Hendel and Lizzeri \(1999\)](#), [Plantin \(2009\)](#), [Kurlat \(2011\)](#) or [Daley and Green \(2011\)](#), obtain persistent effects through learning-by-holding dynamics. In my paper, crises are persistent because the financial sector recovers only by retaining earnings.

A formal model of the interaction between financial intermediation and asymmetric information (in general equilibrium) is the main contribution of this paper. Although this formalism is new, the idea is not: Several decades of research show that net worth affects insurance markets. Liability and catastrophe insurance, for example, share a common striking feature with lending markets. Crises in this sector are recurrent and characterized by large swings premia and volumes. In parallel to the 2008-2009 crisis, these events typically followed episodes of heavy losses for insurance companies.<sup>14</sup> [Gorton and Metrick \(2010\)](#) documents a similar pattern for the shadow banking sector.

Several modeling choices borrow from different papers. Banks here resemble those in [O'Hara \(1983\)](#) or the insurance companies in [Winter \(1991b\)](#). The motive for trade follows from [Kiyotaki and Moore \(2008\)](#). Asymmetric information in asset qualities is introduced in [Bigio \(2011\)](#).

**Empirical Work.** During the recent crisis, there has been considerable empirical investigation that relates to this paper. [Brunnermeier \(2009\)](#), [Krishnamurthy \(2009\)](#), and [Gorton and Metrick \(2010\)](#) suggest that both asymmetric information and bank losses were important factors for its escalation. [Harverd et al. \(2011\)](#) provides evidence on the deterioration of credit quality when banks contract lending during several historical banking crisis episodes. [Ivashina and Scharfstein \(2010\)](#) provide evidence on the decline of volumes of financial intermediation and increased premia. [Acharya et al. \(2010\)](#) detail the behavior of equity injections and dividends. This work suggests that fresh private capital was not flowing to the financial system during those critical times.

## 2 Model

### 2.1 Environment

The model is formulated in discrete time with an infinite horizon. Every period is divided into two stages,  $s \in \{1, 2\}$ . There are two goods: consumption goods (the *numeraire*) and capital goods. Consumption is perishable by the end of the period. There are two aggregate shocks: (1) a TFP shock  $A_t \in \{A_1, A_2, \dots, A_M\}$  realized during the first stage and (2) a shock  $\phi_t \in \Phi \equiv \{\phi_1, \phi_2, \dots, \phi_N\}$  that affects the depreciation of capital realized during the second stage.  $(A_t, \phi_t)$  form a joint Markov process that evolves according to a transition probability  $\chi : (\mathbb{A} \times \Phi) \times (\mathbb{A} \times \Phi) \rightarrow [0, 1]$  with the standard assumptions.

It is worth noting now that in the description to follow, assets are traded during the first stage before the realization of  $\phi_t$ . Claims are settled after the realization  $\phi_t$ , and only then will producers decide on consumption and investment.

**Notation.** I use  $y_{t,s}$  to refer to the value of a variable  $y$  in period  $t$  stage  $s$  when the variable changes value between stages. Otherwise, if the variable remains constant through the period, I use the time subscript only.

**Demography.** There are two populations of agents, producers and bankers, and each population has a

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<sup>14</sup>See [Winter \(1991a\)](#) for a survey on liability insurance market crises. [Gron \(1994b,a\)](#) test the effects of low net-worth on insurance premia and volumes. [Duffie \(2010\)](#) and [Saunders and Cornett \(2010\)](#) describe similar behavior in catastrophe insurance markets.

unit mass. Producers are in charge of productive activities, whereas bankers are intermediaries that facilitate the exchange of capital for consumption goods.

**Producers.** Producers are identified by a number  $z \in [0, 1]$  and carry their capital stock  $k_t(z)$  as an idiosyncratic state variable. Producers have log preferences over consumption streams and evaluate these according to an expected utility criterion:

$$\mathbb{E} \left[ \sum_{t \geq 0} \beta^t \log(c_t) \right],$$

where  $c_t$  is consumption at time  $t$  and  $\beta$  their discount factor.

**Production Activities and Technologies.** At the beginning of the first stage, producers are randomly segmented into two groups, capital-goods producers (k-producers) and consumption-goods producers (c-producers). In particular, producers become k-producers with a probability  $\pi$  independent of time and  $z$ .<sup>15</sup>

A c-producer operates a linear technology during the first stage that produces  $A_t k_t(z)$  units of consumption. Although they have consumption goods, c-producers lack the possibility of augmenting their capital stock by building capital. In contrast, k-producers have access to an investment technology that allows them to produce one unit of new capital with one unit of consumption. New capital is ready for production the following period. The investment technology is operated during the second stage. The capital held by k-producers remains idle, but it can be sold in exchange for consumption.

**Economic Problem.** The segmentation of activities induces a need for trade. On one hand, k-producers need consumption goods to consume and operate the investment technology. C-producers, on the other hand, have consumption goods but lack access to the investment technology. Thus, the economic problem here is that consumption goods must be transferred from c-producers to k-producers, and capital must be reallocated in the opposite direction.

**Capital Units.** At the beginning of the period, capital held by producers is homogeneous. During the first stage, the producer's capital stock is divided into a continuum of units. Each unit is identified by some  $\omega \in [0, 1]$ . The capital of every producer is divided in the same way: they all have the same composition across  $\omega$ 's and only differ in that the scale is proportional to the total capital stock.

These units can be individually reallocated across entrepreneurs. The rate at which units depreciate is given by their  $\omega$  and by the realization of  $\phi_t$ . In particular, there is a function  $\lambda : [0, 1] \times \Phi \rightarrow \mathbb{R}_+$ , such that  $1 - \lambda(\omega, \phi)$  is the depreciation rate of an  $\omega$ -unit when  $\phi$  is the realization of the shock. Once units are scaled by their corresponding  $\lambda(\omega, \phi)$ , they become homogeneous units of  $t+1$  capital. The following period, the capital stock held by producers is divided once again into different  $\omega$ 's, depreciated depending on  $\phi_{t+1}$ , and the process is repeated indefinitely.

The maintained assumption is that  $\lambda(\omega, \phi)$  is increasing in  $\omega$ . This implies that lower  $\omega$ 's depreciate faster. Note that since  $\phi_t$  is only realized during the second stage, the effective depreciation of a given quality is unknown at the first stage. However, producers know that for any realization of  $\phi_t$ , higher  $\omega$ 's depreciate less and, therefore, are of better quality.

By the end of the second stage, the capital that remains for  $t+1$  production from an original  $t$ -period stock  $k$  is  $\tilde{k} = k \int_0^1 \lambda(\omega, \phi_t) d\omega$ . However, producers may choose to sell particular units before the realization of  $\phi_t$ . These decisions are summarized by an indicator function  $\mathbb{I}(\omega) : [0, 1] \rightarrow \{0, 1\}$ .  $\mathbb{I}(\omega)$  takes a value of 1

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<sup>15</sup>Randomization across activities is convenient to reduce the dimension of the state space of the model.



when an  $\omega$ -unit is sold. When a producer chooses  $\mathbb{I}(\omega)$ , he is transferring  $k(z) \int_0^1 \mathbb{I}(\omega) d\omega$  units. These units evolve into  $k(z) \int_0^1 \mathbb{I}(\omega) \lambda(\omega, \phi_t) d\omega$  of  $t+1$  capital after the realization of  $\phi_t$ . Accounting shows that the  $t+1$  that remains with the producer is  $k(z) \int_0^1 [1 - \mathbb{I}(\omega)] \lambda(\omega, \phi_t) d\omega$ . Taking into consideration investments and possible purchases, the producer's capital stock evolves according to:

$$k_{t+1}(z) = i + k^b + k_t(z) \int_0^1 [1 - \mathbb{I}(\omega)] \lambda(\omega, \phi_t) d\omega. \quad (1)$$

In this expression,  $i$  is  $t+1$  capital created by investing (when possible) and  $k^b$  are purchases of  $t+1$  capital.

Given  $\phi$ , the average quality under a certain quality  $\omega^*$  is given by,

$$\mathbb{E}[\lambda(\omega, \phi) | \omega \leq \omega^*] \equiv \frac{\int_0^{\omega^*} \lambda(\omega, \phi) d\omega}{\omega^*}.$$

Let  $\bar{\lambda}(\phi) \equiv \mathbb{E}[\lambda(\omega, \phi) | \omega \leq 1]$  denote the unconditional quality average given  $\phi$ . I impose some structure on  $\lambda(\omega, \phi)$  to provide an interpretation to the  $\phi$  shocks:

**Assumption 1**  $\lambda(\omega, \phi)$  satisfies that  $\mathbb{E}[\lambda(\omega, \phi) | \omega < \omega^*]$  is weakly decreasing in  $\phi$  for any  $\omega^*$ .

The condition above states that the average quality under some cut-off  $\omega^*$  gets worse with larger  $\phi$ .<sup>16</sup> The key friction of the model is that  $\omega$  is private information. For this reason, in equilibrium, producers will sell qualities under an endogenously determined threshold. Assumption 1 implies that the buyer of these units, in this case the banker, is worse off with larger  $\phi$ .

**Private Information.** The  $\omega$ -quality behind a given unit of capital is known only to its owner. This means that a buyer can only observe the size of a pool of units,  $k \int_0^1 \mathbb{I}(\omega) d\omega$ , but cannot discern which  $\omega$ 's are in that pool. After  $\phi$  is realized, the  $t+1$  capital that remains from that pool is  $\int_0^1 \mathbb{I}(\omega) \lambda(\omega, \phi_t) d\omega$ . Therefore, any agent buying capital faces two sources of uncertainty:  $\phi$  is unknown at the time of the purchase as is the  $\omega$ -composition of a given pool. In contrast, producers selling capital only face uncertainty about  $\phi_t$ . At the beginning of the second stage, the quality of a given pool becomes common knowledge and all uncertainty is gone.

This environment is general enough to accommodate two polar cases. The first is when  $\lambda(\omega, \phi)$  is constant across  $\omega$ 's but decreasing in  $\phi$ . In this case,  $\phi$  has the effects of an aggregate depreciation shock.<sup>17</sup>

The second case occurs when  $\bar{\lambda}(\phi)$  is constant, but where the condition in Assumption 1 is strict for  $\omega^* < 1$ . Since in this case  $\bar{\lambda}(\phi)$  is constant, this shock has no effect on the aggregate depreciation and, consequently, neither on the production possibility of the economy. However, since  $\mathbb{E}[\lambda(\omega, \phi) | \omega < \omega^*]$  is decreasing in  $\phi$ , the shock will affect the distribution of resources. As we shall see, this feature has the connotation that if  $\phi$  affects outcomes, it is because it affects equilibrium allocations but not the feasible set of allocations.

**Bankers.** The reallocation of capital units in this economy is intermediated through bankers. Bankers are identified by some  $j \in [0, 1]$ . They have linear preferences over consumption streams and evaluate these according to an expected utility criterion:

$$\mathbb{E} \left[ \sum_{t \geq 0} (\beta^f)^t c_t \right],$$

<sup>16</sup>The assumption applies the definition of first-order-dominance to the conditional expectation function.

<sup>17</sup>This shock has similar effects to the financial shocks studied by Brunnermeier and Sannikov (2011) or Gertler and Karadi (2011).

where  $c_t$  is their consumption and  $\beta^f$  the banker's time discount factor. Bankers own legal institutions called banks. In addition, banks transform one unit of consumption into  $R^b$  units of consumption from the second stage to the following period. Hence, bankers enter the period with  $n_{t,1}(j)$  consumption goods held in their banks.  $n_{t,1}(j)$  is interpreted as the bank's net worth. In addition, at the beginning of every period, bankers receive a large exogenous endowment of consumption goods  $\bar{e}_t(j)$ .  $\bar{e}_t(j)$  is the banker's personal wealth. Although  $\bar{e}$  and  $n$  are both consumption goods, there is an important legal distinction between the two. However, during the first stage, bankers can alter the composition of their wealth by injecting equity from their personal wealth to their banks' net worth, or do the opposite by paying dividends. After equity injections and dividends, their banks' net worth evolves from  $n_{t,1}(j)$  to  $n_{t,2}(j)$ . Bankers consume what remains of their endowment after dividends and equity injections.

Bankers intermediate in the market for capital by purchasing capital units from k-producers during the first stage and reselling them to c-producers during the second stage. Banks fund their capital purchases borrowing consumption goods from c-producers in the first stage and paying back during the second. Formally, they do so issuing tradeable riskless IOUs that entitle the holder to a unit of consumption in the second stage.<sup>18</sup> These IOUs are redeemed by the second period and therefore bear no interest. Bankers buy capital units from k-producers under asymmetric information with the consumption goods obtained from this issuance.

After the shock is realized and depreciation is accounted, the pool of capital bought is resold as a homogeneous  $t+1$  capital. In the process, the law of large numbers holds: given the realization of  $\phi_t$ , the actual average quality of capital bought coincides with the expected quality among the pool of sold units. However, since  $\phi_t$  is realized between stages, this average depreciation is random. This is the source financial intermediation risk. Notice that bankers fund themselves with risk-less liabilities but the value of their capital purchases is risky. Hence, bankers bear all the financial risk. Bankers experience losses if their issued IOUs exceed the market value of the pool of capital they sell.<sup>19</sup>

When a banker experiences losses, he is forced to draw funds from his bank's net worth to honor his liabilities. In principle, financial losses could be financed with the banker's personal wealth also. Instead, this does not happen because financial intermediation is subject to limited liability. A banker's personal wealth is then not liable to his bank's losses. If IOUs are risk free, this imposes a limited-liability constraint (LLC): losses from financial intermediation cannot exceed his bank's net worth under any contingency.<sup>20</sup> Consequently, the bank's net worth will restrain the amount of capital that banker's can buy. The greater the amount of capital bought, the greater the risk and the greater the need for net worth as a cushion to support losses. Thus, the distinction between a banker's personal endowment and his bank's equity arises only because his net worth relaxes the LLC constraint.<sup>21</sup> However, since bankers can choose to inject equity from their personal endowment, they can relax that constraint at will. In equilibrium, they must have the right incentives to do so.

Bankers face an exogenous constant probability of exit,  $\rho$ . When,  $\rho = 0$ , bankers are characterized by

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<sup>18</sup>In a later section I explain how this institutional environment can be reinterpreted to resemble commercial bank practices. Introducing banks as dealers is done for pedagogical reasons.

<sup>19</sup>A similar trading arrangement arises endogenously in [Haubrich and King \(1990\)](#) and [Calomiris and Kahn \(1991\)](#) when banks have additional incentive problems.

<sup>20</sup>Equivalently, this a *solvency* or *non-default* constraint.

<sup>21</sup>In [He and Krishnamurthy \(2009\)](#) or [Brunnermeier and Sannikov \(2011\)](#), this LLC is obtained endogenously when bankers lack commitment. If bankers cannot be forced to inject equity into their banks to cover losses, this constraint shows up as an ex-post incentive-compatibility condition. Otherwise, this constraint can be obtained from a high penalty for bankruptcy or defaulting on IOUs resulting from reputation concerns. Finally, as shown later, one can take the LLC as a legal constraint (i.e., leverage constraints).

an infinite-horizon problem. When  $\rho = 1$ , bankers live one period, and one can solve the model analytically. When a banker exits, he is immediately replaced by a newborn banker. Upon exit, bankers sell their bank to an entrant banker.

**Public Information.** There are two endogenous aggregate states:  $K_t = \int_0^1 k_t(z) dz$  and  $N_{t,s} = \int_0^1 n_{t,s}(j) dj$ . These states are the aggregate capital stock and the net worth of the financial sector respectively. It is only necessary to keep track of their ratio  $\kappa_{t,s} \equiv N_{t,s}/K_t$ , the relative size of the financial sector, as an aggregate endogenous state variable. Since  $\kappa$  determines the capacity to bear losses relative to the wealth of producers, I refer to it as the *financial risk capacity*. Thus, the aggregate state of this economy is summarized by  $X_{t,1} = \{A_t, \phi_{t-1}, \kappa_{t,1}\} \in \mathbb{X} \equiv \mathbb{A} \times \Phi \times \mathbb{K}$  and  $X_{t,2} = \{A_t, \phi_t, \kappa_{t,2}\} \in \mathbb{X} \equiv \mathbb{A} \times \Phi \times \mathbb{K}$ . At every point,  $X_{t,s}$  is common knowledge. For tractability, I assume that the producer's type is known. This assumption ensures that, in equilibrium, c-producers are excluded from selling capital. Bankers are informed about their exit at the beginning of the second stage.

**Markets.** The only possible transactions are purchases and sales of capital intermediated by bankers, as described earlier, and the issuance of IOUs for consumption goods. There are two markets for capital. The first is the one where capital units are sold by k-producers and bought by banks under asymmetric information. This market opens during the first stage and satisfies the following assumption:

**Assumption 2** *Capital markets are **anonymous** and **non-exclusive**. Banks are **competitive**.*

Without anonymity, bankers could pay different prices depending on the volume of capital sold. With exclusivity, bankers could use dynamic incentives to screen. Assumption 2 therefore implies that the market in the first stage is a pooling market. Hence, there is a unique pooling price  $p_t$  in this market.<sup>22</sup> I refer to it as the pooling market. The assumption that banks are competitive means that they take prices (and traded qualities) as given.

The second market opens during the second stage. This is the market in which bankers sell back all the units purchased during the first stage. Effectively, this is a market for  $t+1$  homogeneous capital. This market clears at a price  $q_t$ . I refer to it as the resale market.

**Timing.** The summary of the timing is the following. At the beginning of the period,  $A_t$  is realized and observed by all. Then, consumption goods is produced by c-producers. Bankers decided over equity injections and dividend payouts.  $\kappa_{t,1}$  is updated and observed by all. Then, bankers obtain consumption goods issuing IOUs and use these funds to buy capital under asymmetric information. K-producers, in turn, choose which qualities to sell in the pooling market. During the second stage,  $\phi_t$  is realized and  $X_{t,2}$  is updated. Bankers learn the average quality of the capital they bought and resell the pool as homogeneous  $t+1$  capital. By the end of the period, bankers settle claims against all issued IOUs realizing profits or losses. All producers simultaneously choose over consumption and purchases of capital, and k-producers also decide on the scale of investment.

The timing of the model is summarized by Figure 2. The following section describes the problem faced by the agents in this economy and the corresponding market-clearing conditions that define equilibria. This economy has a recursive representation, so from now on, I drop time subscripts. I use  $x'$  to denote the value of a variable  $x$  in the subsequent stage. I denote by  $n$  bank equity brought from the previous period.  $n'$  is bank equity after equity injections and dividends brought from stage 1 to stage 2.  $n''$  is the bank equity after realizing profits in the second stage and taken to the subsequent period. The same notation is used for  $\kappa$ .

<sup>22</sup>In a similar problem, [Guerrieri and Shimer \(2011\)](#) allow agents to trade in multiple markets for which capital is exchanged with some probability. Differences in probability and prices allow for separation.

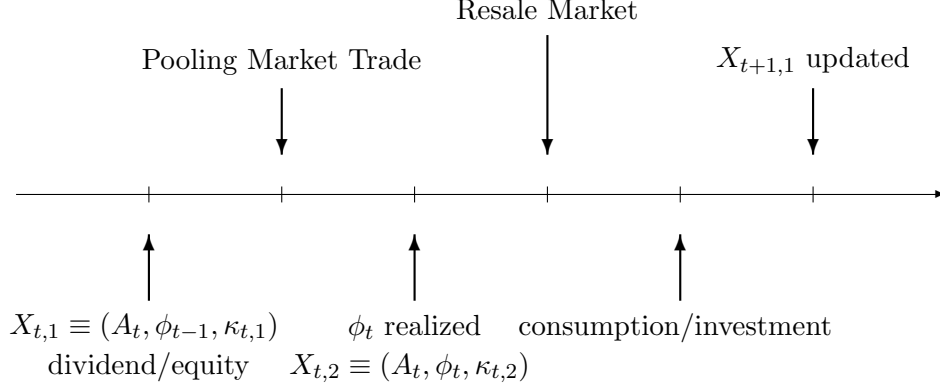


Figure 2: **Timing**

## 2.2 First-Stage Problems

**K-producer's First Stage.** During the first stage, a  $k$ -producer enters the period with a capital stock  $k$ . At this stage, his only decision is about which qualities to sell:

**Problem 1** ( $k$ -producer's  $s=1$  problem) *The  $k$ -producer's first stage problem is:*

$$V_1^k(k, X) = \max_{\mathbb{I}(\omega) \in \{0,1\}} \mathbb{E} \left[ V_2^k(k'(\phi'), x, X') | X \right]$$

$$\text{subject to } x = pk \int_0^1 \mathbb{I}(\omega) d\omega \text{ and } k'(\phi') = k \int [1 - \mathbb{I}(\omega)] \lambda(\omega, \phi') d\omega$$

The first equation is the  $k$ -producer's budget constraint.  $x$  is the quantity of consumption goods available during the second stage. This is obtained by selling  $k \int_0^1 \mathbb{I}(\omega) d\omega$  units of capital at a pooling price  $p$ . The second equation accounts for the following period's capital stock that remains with him. The solution to this problem determines a supply schedule for capital units in the pooling market.

**C-producer's First Stage.** Since  $c$ -producers are excluded from the pooling market, they take no actions in this stage. Their value function is the expected value of their second stage's value function:

**Problem 2** ( $c$ -producer's  $s=1$  problem) *The  $c$ -producer's first stage value function:*

$$V_1^c(k, X) = \mathbb{E} \left[ V_2^c(k'(\phi'), x, X') | X \right]$$

$$\text{where } x = Ak \text{ and } k'(\phi') = k \int \lambda(\omega, \phi') d\omega$$

**Banker's First Stage.** A banker enters the period with  $n$  consumption goods stored in his bank and  $\bar{e}$  as a personal endowment. A banker chooses an amount from his endowment  $e$  as equity injections to his bank at the expense of decreasing consumption. He can reduce his bank's net worth by transferring  $d$  consumption units as dividends to be consumed after dividend taxes  $\tau$ . Equity injections and dividends are limited by their sources:  $e \in [0, \bar{e}]$  and  $d \in [0, n]$ . In this paper I focus on equilibria in which  $e \leq \bar{e}$  never binds with the interpretation that there are always resources available to recapitalize banks. The banker's consumption

is  $c = (\bar{e} - e) + (1 - \tau) d$ . His bank's net worth is transformed instantaneously according to  $n' = n + e - d$ . The presence the dividend tax is introduced to obtain inaction regions for the banker's financial policy.<sup>23</sup>

Let  $Q$  be the volume of capital units purchased by a banker in the pooling market. He funds this purchases by issuing IOUs at face value  $pQ$ . These IOUs bear no interest and are redeemed by the second stage. During the second stage, the value of the capital pool purchased is  $q\mathbb{E}[\lambda(\omega, \phi') | X] Q$ . The resale market trades following-period capital at a resale price  $q$ . The  $Q$  units are purchased in the current period, so these units are scaled by their average depreciation,  $\mathbb{E}[\lambda(\omega, \phi') | X]$ , to count them as following period capital.  $\mathbb{E}[\lambda(\omega, \phi') | X]$  results from  $\phi$  and the  $\mathbb{I}(\omega)$ -policies that depend on  $X$ .

The LLC states that the amount of issued IOUs cannot exceed the bank's net worth plus the value of this capital under any realization of  $\phi'$ :

$$pQ \leq q\mathbb{E}[\lambda(\omega, \phi') | X] Q + n' \text{ for any } (X, X') \in \mathbb{X} \times \mathbb{X}$$

Let  $\Pi(X, X') \equiv q\mathbb{E}[\lambda(\omega, \phi') | X] - p$  be the banker's marginal profit from intermediation.  $\Pi(X, X')$  is a function of  $X$  and  $X'$  since qualities sold depend on  $X$ , but their depreciation depends on  $X'$  through  $\phi'$ . The banker's problem is,

**Problem 3** *The banker's first stage problem is:*

$$\begin{aligned} V_1^f(n, X) &= \max_{Q, e \in [0, \bar{e}], d \in [0, n]} c + \mathbb{E} \left[ V_2^f(n' + \Pi(X, X') Q, X') | X \right] \\ \text{subject to } & -\Pi(X, X') Q \leq n', \forall X' \\ & c = (\bar{e} - e) + (1 - \tau) d \\ & n' = n + e - d \end{aligned} \tag{2}$$

The first constraint is the LLC. The second and third constraints are the banker's budget constraints and the law of motion of his net worth.

## 2.3 Second-Stage Problems

**K-producer's Second Stage.** During the first stage, k-producers have sold part of their capital stocks in exchange for  $x$  consumption goods brought into the current. They also bring the  $k$  capital units they did not sell. Given their idiosyncratic and the aggregate states, they solve,

**Problem 4** (*i-entrepreneur's  $s=2$  problem*) *The k-producer's problem in the second stage is:*

$$\begin{aligned} V_2^k(k, x, X) &= \max_{c \geq 0, i, k^b \geq 0} \log(c) + \beta \mathbb{E} \left[ V_1^k(k', X') | X \right], \quad j \in \{i, p\} \\ \text{subject to } & c + i + qk^b = x \text{ and } k' = k^b + i + k \end{aligned}$$

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<sup>23</sup> A distinction between costly equity injections and dividend taxes is common in the dynamic corporate finance literature. See examples, [Hennessy and Whited \(2005\)](#) and [Palazzo \(2010\)](#), among others. In this environment, only the ratio of the cost of equity and dividend taxes matters, so I normalize the tax rate to account for this differences.

This budget constraint says that the k-producer uses  $x$  to consume  $c$ , invest  $i$ , or purchase  $k^b$  capital at price  $q$ . The capital accumulation equation is consistent with equation (1) since  $k$  already incorporates sales and depreciation (accounted in the previous stage).

**C-producer's Second Stage.** The c-producer's problem is identical to the k-producer's, except when the c-producer is restricted to set  $i \leq 0$  because he lacks the investment technology:<sup>24</sup>

**Problem 5** (*p-entrepreneurs s=2 problem*) *The c-producer's problem at the second stage is:*

$$V_2^c(k, x, X) = \max_{c \geq 0, i \leq 0, k^b \geq 0} \log(c) + \beta \mathbb{E} \left[ V_1^j(k', X') | X \right], \quad j \in \{i, p\}$$

$$\text{subject to } c + i + qk^b = x \text{ and } k' = k^b + i + k$$

**Banker's Second Stage.** A banker's only action during the second stage consists on reselling all the capital units purchased during the first stage after accounting for their depreciation. Thus, their value is  $V_2^f(n, X) = \beta^F \mathbb{E} \left[ V_1^f(R^b n, X') | X \right]$  if they remain in the industry or  $V_2^f = (1 - \tau) \beta^F R^b n$  if they exit.

## 2.4 Market-Clearing Conditions and Equilibrium

**Notation.** I append terms like  $j(k, X)$  to variables that indicate the policy function of a producer of type  $j$  in state  $(k, X)$ . I use  $\mathbb{I}(\omega, k, X)$  to refer to a k-producer's decision to sell an  $\omega$ -quality when his state is  $(k, X)$ .

**Aggregation.** In every period and stage, there are measures over capital holdings across the population of k and c-producers. I denote these measures by  $\Gamma^k$  and  $\Gamma^c$  respectively. By independence of the producer's activities, these satisfy:

$$\int_0^\infty \Gamma^k(dk) = \pi K \quad \text{and} \quad \int_0^\infty \Gamma^c(dk) = (1 - \pi) K. \quad (3)$$

Their evolution is consistent with individual decisions and the activity segmentation process. In addition, there is also a measure  $\Lambda$  for the bankers net worth.

**First Stage.** Market clearing during the first stage requires that the demand for capital by bankers be equal to the supply of capital by k-producers. This condition is given by:

$$\int_0^\infty Q(n, X) \Lambda(dn) = \int_0^\infty k \int_0^1 \mathbb{I}(\omega, k, X) d\omega \Gamma^k(dk)$$

**Second Stage.** The demands for following-period capital by c- and k-producers are respectively:

$$D^c(X, X') \equiv \int_0^\infty k^{b,c} \left( x(k, X), k \int_0^1 \lambda(\omega, \phi') d\omega, X' \right) \Gamma^c(dk)$$

and

$$D^k(X, X') \equiv \int_0^\infty k^{b,k} \left( x(k, X), k \int_0^1 [1 - \mathbb{I}(\omega, k, X)] \lambda(\omega, \phi') d\omega, X' \right) \Gamma^k(dk).$$

Bankers sell all the units bought, so the supply of capital in the second stage is:

$$S(X, X') \equiv \mathbb{E} [\lambda(\omega, \phi') | X] \int_0^\infty Q(n, X) \Lambda(dn).$$

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<sup>24</sup>Investment reversibility is introduced for tractability.



The market clearing condition in the second stage is  $S(X, X') = D^c(X, X') + D^k(X, X')$ . A recursive competitive equilibrium is:

**Definition 1** (Recursive Competitive Equilibrium) *A recursive competitive equilibrium (RCE) is (1) a set of price functions,  $\{q(X, X'), p(X)\}$ , (2) a set of policy functions for  $c$ -producers  $c^c(x, k, X)$ ,  $k^{b,c}(x, k, X)$ ,  $i^c(x, k, X)$ , a set of policy functions for  $k$ -producers  $c^k(x, k, X)$ ,  $k^{b,k}(x, k, X)$ ,  $\mathbb{I}^k(\omega, k, X)$ , a set of policy functions for bankers  $Q(n, X)$ ,  $e(n, X)$ ,  $d(n, X)$ , (3) sets of value functions,  $\{V_1^l(k, X), V_2^l(x, k, X)\}_{l=c,k}$ ,  $\{V_s^f(n, X)\}_{s=1,2}$ , and (4), a law of motion for the aggregate state  $X$ , such that for any measures  $\Gamma^c$ ,  $\Gamma^k$  and  $\Lambda$  satisfying the consistency condition (3) the following hold: (I) The producers' policy functions are solutions to their problems taking  $q(X, X')$ ,  $p(X)$  and the law of motion for  $X$  as given. (II)  $Q(n, X)$ ,  $e(n, X)$ ,  $d(n, X)$  are solutions to the Bankers problem taking  $q(X, X')$ ,  $p(X)$  and the law of motion for  $X$  as given. (III) Capital markets clear during the first and second stages. (IV) The law of motion  $X$  is consistent with policy functions and the transition function  $\chi$ . All expectations are consistent with the law of motion for  $X$  and agent policies.*

The definition of equilibrium does not depend on the measures of asset holdings because this economy admits aggregation. This is shown once I characterize the solution. However, there is an important detail: Nothing precludes multiplicity. This occurs because for a given  $X$  during the first stage, there could be two or more equilibrium triplets  $(\omega, Q, p(X), q(X, X'))$  that satisfy the conditions for equilibrium. The source of multiplicity is that as prices increase, both the average quality of capital sold and the quantity increase. In consequence, bank profits are possibly non-monotone. This leads to the possibility of finding the same worst-case-scenario profits for two different equilibrium prices. Multiplicity is a common feature in static models of asymmetric information. Although multiplicity is an interesting phenomenon in and of itself, it is not the focus of this paper. For the rest of the paper, I introduce an equilibrium refinement:

**Definition 2** (Pareto Un-improvable Equilibrium) *A RCE is Pareto un-improvable if given the law of motion for  $X$ ,  $\forall X$ , there does not exist any  $p^o > p(X)$ , such that  $p^o$  satisfies market clearing in the first stage, and induces a second stage market clearing price  $\tilde{q}(p, X')$  that is consistent with the producer's policy functions and the LLC.*

This refinement selects the RCE where the volume of intermediation is greatest. A later section shows that such equilibria cannot be Pareto improved upon. We need to show some intermediate results first. Before proceeding to the characterization, I provide a description of alternative interpretations of the LLC constraint and financial intermediation.

### 3 Discussion

This section discusses the role of banks in the model. The following section proceeds to the characterization of equilibria.

#### 3.1 Intermediation Arrangements

Note that banks here play two of the several roles stressed by banking theory (see Freixas and Rochet, 2008, section 1.2). First, they manage risks because they pool capital together. Second, they transform assets because they offer risk-free claims to fund risky positions. This financing structure arises optimally in Gorton

and Pennacchi (1990). Here, this is presumably optimal given that they are risk neutral and producers are risk-averse. Notice that this role is different from the more common roles of delegated monitoring (see Diamond, 1984) or maturity transformation (see Diamond and Dybvig, 1983) stressed by the literature.

This intermediation arrangement is justified by some implicit assumptions. First, I assume that only bankers can buy a large number of capital units and can thus pool qualities together. By buying a large amount of units, they can eliminate all the idiosyncratic risk that occurs if an agent buys a small sample of capital units (drawn from the pool qualities sold).<sup>25</sup> Second, I implicitly assume that because managerial incentives cannot be met, bankers will never hold onto capital with the purpose of selling in later periods.<sup>26</sup>

If banks offer risk-free securities while bearing risks on their assets side, they must satisfy the LLC described in this paper. Diamond and Rajan (2000) describe a model where the composition between bank equity and risk-less debt arises endogenously given a trade off. In their environment deposits discipline bank behavior whereas bank capital acts like a buffer against negative shocks.

### 3.2 Accounting and Financial Constraints

**Bank Balance Sheets.** During the first stage, bankers have net worth  $n$  held in their banks. At the beginning of the stage, they alter their bank's balance sheet by injecting equity or paying dividends. In addition, the bank increases liabilities by issuing  $pQ$  in IOUs and accumulates assets by purchasing pools of capital. From the beginning to the end of the first stage, their banks' balance sheets evolves in the following way:

$$\begin{array}{c}
 \begin{array}{|c|c|} \hline \text{Assets} & \text{Liability} \\ \hline n & \\ \hline & \text{Net worth} \\ \hline & n \\ \hline \end{array} & \Rightarrow & \begin{array}{|c|c|} \hline \text{Assets} & \text{Liability} \\ \hline n + e - d & pQ \\ \hline pQ & \text{Net worth} \\ \hline & n + e - d \\ \hline \end{array} = & \begin{array}{|c|c|} \hline \text{Assets} & \text{Liability} \\ \hline n' & pQ \\ \hline pQ & \text{Net worth} \\ \hline & n' \\ \hline \end{array} . \\
 \text{Beginning-of-period Balance Sheet} & & \text{End-of-stage-1 Balance Sheet} & & \text{End-of-stage-1 Balance Sheet}
 \end{array}$$

After  $\phi$  is realized, the value of the assets in the balance sheet adjusts as both, the quality and the price of capital respond to  $\phi$ . The *mark-to-market* value of capital may then differ from the amount of IOUs issued. The issuance of IOUs is a form of inside liquidity and are effectively deposit contracts. Accounting for these changes in values, the following balance sheet changes to:

$$\begin{array}{|c|c|} \hline \text{Assets} & \text{Liability} \\ \hline n' & pQ \\ \hline q\mathbb{E}[\lambda(\omega, \phi') | X] Q & \text{Net worth} \\ \hline & n' + \Pi Q \\ \hline \end{array} .$$

End of stage 2 Balance Sheet

<sup>25</sup>Boyd and Prescott (1986) present an environment with privately informed parties, where coalitions of agents form large intermediaries that play this precise role. Williamson (1986, 1987) are early business cycle model where banks play a similar role in transforming assets by lending to privately informed agents and borrowing through deposits.

<sup>26</sup>However, the model can be extended in this direction. The outcome involves a non-trivial fire-sale behavior for financial firms that, in turn, may have implications for the behavior of the financial system. Fire-sales may induce a different type of externality than the one caused by adverse selection, which is the focus of this paper. See Brunnermeier and Sannikov (2011) or Diamond and Rajan (2011) for examples.

In this balance sheet, net worth is adjusted by gains or losses from financial intermediation  $\Pi(X, X')Q = (q\mathbb{E}[\lambda(\omega, \phi')|X] - p)Q$ . The evolution of these balance sheets is similar to the description of commercial banks found in any banking text book.

### 3.3 Commercial Banking Interpretation

The institutional environment in this model can be interpreted directly in terms of investment banking since banks are traders of capital. However, the model can be reinterpreted as a model of commercial banking by introducing collateral contracts with default in a similar way as in [Kocherlakota \(2001\)](#). I omitted this representation from the description of the environment to simplify the analysis. However, it is worth discussing this point. So far, the liability side resembles commercial bank deposit contracts. The operations on the asset side do not, however, because commercial banks grant loans rather than buying capital units directly. Variables on the asset side, however, can be reinterpreted as *ad-hoc* collateralized loan contracts instead of capital purchases. For that purpose, assume  $Q$  represents units of capital used as a collateral that guarantees a loan, and  $p$  the corresponding amount lent per unit of collateral. A collateralized loan contract also specifies an amount  $R^L$  per unit of collateral in return for the loan. This return is settled during the second stage. Upon the borrower's failure to repay, collateral is seized and sold to c-producers. One obtains the same equilibrium allocations as in the environment with sales if the return is set to  $R^L(X) = \max_{\phi'} q\mathbb{E}[\lambda(\omega, \phi')|X]$ . The reason is if this is the repayment scheme, in states in which  $\phi = \phi_1$ , k-producers are then indifferent between repaying loans and defaulting. In non-default states, producers can obtain funds to repay  $R^L\omega$  by selling the capital that was used as collateral. With these sales, they obtain the face value of debt needed to settle their loans. In contrast, defaults occur if  $\phi > \phi_1$  because the producer would rather loose his collateral than repay the face value of debt. In that case, banks seize the capital units and sell them for  $q\mathbb{E}[\lambda(\omega, \phi')|X]$ . For any value of  $\phi$ , the flow of resources in this economy are the same as in the environment with purchases and sales.

Similar collateralized loan contracts that deliver countercyclical defaults are optimal outcomes in [Rampini \(2005\)](#).<sup>27</sup> However, unless additional structure is introduced, this implementation is ad-hoc because the terms of the contract are not-necessarily the optimal ones. Deriving the optimal contract is left for future work.

### 3.4 Interpreting LLC as Regulatory Constraints

**LLC as a Leverage Constraint.** The LLC can be expressed as a constraint on leverage. Arranging terms in equation (2) leads to:

$$\underbrace{\frac{Q}{n'}}_{\text{Net worth}} \leq \underbrace{\frac{1}{- [q(X', X) \mathbb{E}[\lambda(\omega, \phi')|X] - p(X)]}}_{\text{Marginal Leverage Constraint}}, \forall X'.$$

The term on the right is the marginal leverage: When the LLC binds, an additional unit of net worth allows the producer to increase  $Q$  in that amount.<sup>28</sup> Multiplying by  $p(X)$  and adding 1 to both sides leads to an

<sup>27</sup>Also, [DeMarzo and Duffie \(1999\)](#) show that collateralized debt contracts are optimal when the return to assets that back security issuances have a private information component. [Lacker \(2001\)](#) finds a similar result when borrowers value their collateral more than lenders.

<sup>28</sup>Note that when  $- [q(X', X) \lambda(\phi) - p(X)] < 0$ , the constraint is trivially satisfied.

equivalent constraint expressed in terms of the bank's leverage:

$$\underbrace{\underbrace{p(X)Q + n'}_{\text{Net worth}}}_{\text{Leverage}} \leq \underbrace{\frac{p(X)}{-[q(X', X) \mathbb{E}[\lambda(\omega, \phi') | X] - p(X)]}}_{\text{Total Leverage Constraint}} + 1, \quad \forall X'.$$

The Basel Accords impose constraints on bank leverage.<sup>29</sup> I return to this point later on when I study the effects of capital requirements.

**LLC as Value at Risk (VaR).** The LLC can be manipulated to obtain a constraint in terms of the Value at Risk of bank net worth. The LLC constraint states that  $n' + \Pi(X', X)Q = n'' \geq 0$  for any possible realization of  $\phi'$ . Given  $X$ , the worst outcome is realized with some probability  $\eta$  that depends on  $\phi$ . Thus, the LLC states that the value of net worth at its  $\eta$ -percentile must be greater than 0. Letting  $VaR(b, \eta)$  denote the value of a random variable  $b$  at its  $\eta$ -percentile, the LLC can be expressed as  $VaR(n'', \eta) \geq 0$ . The Basel Accords require banks to satisfy constraints in terms of the Value at Risk of their portfolios. Thus, the LLC can be adapted to capture these regulatory constraints.<sup>30</sup>

## 4 Characterization

### 4.1 Policy Functions

**Producers' Second-Stage Policies** I begin the characterization of equilibria by describing the policy functions of c-producers. As a result of log-preferences, the c-producer's policy functions are linear functions of his virtual wealth  $W^c(k, x, X) \equiv (A + q\bar{\lambda}(\phi'))k$ . His virtual wealth is the sum of his produced consumption goods and the market value of his capital stock.

**Proposition 1** *In any RCE, the c-producer's policy functions are  $k^{c'}(k, x, X) = \beta \frac{W^c(k, x, X)}{q}$  and  $c^c(k, x, X) = (1 - \beta)W^c(k, x, X)$  and his value function is of the form  $V_2^c(k, x, X) = \psi^c(X) + \log(W^c(k, x, X))$  where  $\psi^c(X)$  is a function of the aggregate state.*

Policy functions for k-producers are also linear in their corresponding virtual wealth,  $W^k(k, x, X) \equiv (x + q^i \mathbb{E}[\lambda(\omega, \phi') | \omega < \omega^*(X)])k$ . The k-producer's virtual wealth per unit of capital is the sum of the consumption goods obtained by selling capital units,  $x$ , and the replacement value of his remaining units. The average depreciation of the units he keeps is  $\mathbb{E}[\lambda(\omega, \phi') | \omega < \omega^*(X)]$ . This is the average depreciation under that of a cut-off quality kept  $\omega^*(X)$ . The following section shows that, indeed, his capital sales policies are characterized by a threshold quality. The replacement cost of their capital is  $q^i = \min\{1, q\}$ .  $q^i$  takes this form because k-producers will produce capital at a unit cost when  $q > 1$ . If  $q^i \leq 1$ , the k-producers may purchase capital from banks instead of investing. Hence,  $q^i$  is the lowest cost of accumulating capital for them. Their policy functions are given by:

**Proposition 2** *In any RCE, the k-producer's policy functions are  $k^{k'}(k, x, X) = \beta \frac{W^k(k, x, X)}{q^i}$  and  $c^k(k, x, X) = (1 - \beta)W^k(k, x, X)$  and his value function is of the form  $V_2^k(k, x, X) = \psi^k(X) + \log(W^k(k, x, X))$  where  $\psi^k(X)$  is a function of the aggregate state.*

<sup>29</sup>See *Basel Committee on Banking Supervision* (2010).

<sup>30</sup>See *Basel Committee on Banking Supervision* (2010).

**Producers' First-Stage Policies.** One can use Proposition 2 to obtain a closed-form expression for the  $k$ -producer's value function during the first stage. Replacing the definitions of  $x$  and  $\mathbb{E}[\lambda(\omega, \phi') | \omega < \omega^*(X)]$ , their value function is:

$$V_1^k(k, X) = \max_{\mathbb{I}(\omega) \in \{0,1\}} \mathbb{E} \left[ \log \left( p(X) \int_0^1 \mathbb{I}(\omega) d\omega + q^i(X, X') \int \lambda(\omega, \phi') [1 - \mathbb{I}(\omega)] d\omega \right) | X \right] + \psi^k(X) + \log(k).$$

Through this expression, it is clear that quality-sales decisions have to be the same across entrepreneurs regardless of the size of their capital stock. These decisions are characterized by a portfolio problem:

**Proposition 3** *In any RCE, the  $k$ -producer's policy function in the first stage is given by,  $\mathbb{I}^*(\omega, k, X) = 1$  if  $\omega < \omega^*$  and 0 otherwise. The cut-off quality is given by:*

$$\omega^* = \arg \max_{\tilde{\omega}} \mathbb{E} \left[ \log \left( p\tilde{\omega} + q^i(X, X') \int_{\tilde{\omega}}^1 \lambda(\omega, \phi') d\omega \right) | X \right]. \quad (4)$$

Moreover,  $\omega^*$  is increasing in  $p$ .

Proposition 3 shows that the solution to the producer's problem during the first stage is characterized by a unique cut-off quality such that units of inferior quality are sold. This outcome resembles the solution to lemons problem of Akerlof (1970), but there is a distinction. In the original lemons problem, the cut off is the quality for which the seller is indifferent between selling or keeping the asset. Here,  $\omega^*$  is chosen by solving a portfolio problem because the producer does not know the outcome of  $\phi$  when selling capital. This portfolio problem has an intuitive interpretation:  $\omega^*$  is the fraction of the producer's capital stock sold to banks. Once he exchanges these units, the producer loads the depreciation risk to the bank. In doing so,  $\omega^*$  becomes the risk-less portion of his portfolio. The remaining fraction,  $(1 - \omega^*)$ , is risky because  $\phi'$  is realized after  $\omega^*$  is chosen. Since,  $\omega^*$  is increasing in  $p(X)$ , the supply of capital has a typical upward sloping form.

**Remark 1**  $\omega^*(X)$  indicates the highest quality of capital traded and the volume of intermediation.

Thus, from now on, I use threshold quality and volume of intermediation to refer to  $\omega^*$  interchangeably.

**Bankers' policies.** At the beginning of every period, bankers choose  $e, d$  and  $Q$  to maximize expected profits. The following Proposition shows that their value function and policies are linear in  $n$ :

**Proposition 4** *The banker's value function is a linear function of  $n$  :  $V_1^f(n, X) = v_1^f(X)n$  and  $V_2^f(n, X) = v_2^f(X)n$  where  $v_1^f(X)$  and  $v_2^f(X)$  are the marginal value of financial equity in stages 1 and 2 respectively.  $v_1^f(X)$  solves the following Bellman equation:*

$$v_1^f(X) = \max_{Q \geq 0, e \in [0, \bar{e}], d \in [0, 1]} (1 - \tau)d - e + \mathbb{E} \left[ v_2^f(X') \left( \Pi(X, X')Q + n' \right) | X \right] \quad (5)$$

subject to,

$$\begin{aligned} -\Pi(X, X')Q &\leq n', \forall X' \\ n' &= 1 + e - d. \end{aligned}$$

The Bellman equation (5) is solved by linear optimal policies,  $e(X)$ ,  $d(X)$  and  $Q(X)$  given by:

$$e(n, X) = e^*(X) n, \quad d(n, X) = d^*(X) n, \quad Q(n, X) = Q^*(X) (1 + e^*(X) - d^*(X)) n.$$

In addition,  $v_2^f(X) = \beta^F R^b$  if the banker exits and  $v_2^f(X) = \beta^F \mathbb{E} [v_1^f(X) R^b]$  otherwise.

The value function of the banker is linear in his net worth because of risk-neutrality and the linearity of the LLC. In equilibrium, there may be multiple solutions to  $d(n, X)$  and  $e(n, X)$  but, without loss of generality, I restrict the attention to linear policies. The following proposition describes them:

**Proposition 5**  $Q^*(X)$  is given by,

$$Q^*(X) = \arg \max_{\tilde{Q}} \mathbb{E} [v_2^f(X') \Pi(X, X') | X] \tilde{Q} \text{ subject to } \Pi(X, X') \tilde{Q} \leq 1, \forall X'.$$

In equilibrium,  $\min_{\tilde{X}} \Pi(X, \tilde{X}) < 0$ , and  $(e^*(X), d^*(X))$ , satisfy:

$$\begin{aligned} e^*(X) &> 0 \text{ only if } \beta^F \left[ \mathbb{E}[v_2^f(X')] + \max \left\{ \frac{\mathbb{E}[v_2^f(X') \Pi(X, X')]}{-\min_{\tilde{X}} \Pi(X, \tilde{X})}, 0 \right\} \right] \geq 1 \\ d^*(X) &> 0 \text{ only if } \beta^F \left[ \mathbb{E}[v_2^f(X')] + \max \left\{ \frac{\mathbb{E}[v_2^f(X') \Pi(X, X')]}{-\min_{\tilde{X}} \Pi(X, \tilde{X})}, 0 \right\} \right] \leq (1 - \tau). \end{aligned}$$

When the inequalities are strict,  $e = \bar{e}$  and  $d = 1$ .  $e^*(X)$  and  $d^*(X)$  are indeterminate at the individual level when the relations hold with equality.  $e^*(X)$  and  $d^*(X)$  equal 0 when the inequalities are violated.

This proposition states that the LLC is binding whenever  $\mathbb{E} [v_2^f(X') \Pi(X, X') | X] > 0$ .  $v_2^f(X') \Pi(X, X')$  is the marginal value of an additional unit of intermediation in state  $X'$ . This term is the product of marginal profits and the marginal value of bank equity.  $v_2^f(X')$  fluctuates because it summarizes future expected returns to bank equity, which depends on  $X'$ . When,  $\mathbb{E} [v_2^f(X') \Pi(X, X') | X] = 0$ ,  $Q$  is indeterminate: The banker is indifferent between any volume of intermediation.  $Q$  is 0 when this term is negative.

The proposition also states conditions for capital injections and dividend payoffs. These financial policies depend on the marginal value of keeping equity in the bank:

$$\tilde{v}(X) \equiv \beta^F \left[ \mathbb{E}[v_2^f(X')] + \max \left\{ \frac{\mathbb{E}[v_2^f(X') \Pi(X, X')]}{-\min_{\tilde{X}} \Pi(X, \tilde{X})}, 0 \right\} \right]. \quad (6)$$

$\tilde{v}(X)$  has an intuitive interpretation.  $\beta^F$  is the discount factor of future utility. The first term inside the bracket,  $\mathbb{E}[v_2^f(X')]$ , is the future marginal value of an additional unit of equity. In a risk-neutral environment such as this one, this term is the bank's stochastic discount factor. The second term represents the shadow value of equity obtained from relaxing the LLC. As explained earlier, the inverse of the worst-case scenario losses,  $-\min_{\tilde{X}} \Pi(X, \tilde{X})$ , is the bank's marginal leverage. Increasing a unit of equity allows the bank to issue this amount in IOUs to purchase capital. This additional units of capital have an expected marginal value of  $\mathbb{E}[v_2^f(X') \Pi(X, X')]$ , which is the marginal value of an additional unit of intermediation. The max operator sets this marginal value to 0 when  $\mathbb{E}[v_2^f(X') \Pi(X, X')] < 0$ .



When  $\tilde{v}(X) < (1 - \tau)$ , the banker prefers to pay out dividends: the marginal value of equity is  $\tilde{v}(X)$ , but the after-tax marginal benefit of dividends is higher. In contrast, the banker injects equity to his bank when the value of holding equity exceeds one, the opportunity cost of equity in terms of foregone consumption. This result implies that banks have (S,s)-bands for their dividend policies with  $[(1 - \tau), 1]$  as the inaction region. The properties of these regions are discussed in more detail in the following section.

The following section shows that in absence of asymmetric information,  $\tilde{v}(X)$  is, in fact, monotone decreasing in  $\kappa$ . However, if asymmetric information is sufficiently severe,  $\tilde{v}(X)$  is non-monotone. This non-monotonicity leads to multiple inaction regions. In turn, this feature explains why the financial sector is not recapitalized for low levels of  $\kappa \equiv N/K$  even though recapitalization does not occur at higher levels. This results from  $\Pi(X, X')$  being non-monotone in  $\kappa$  when asymmetric information is severe. To show this result formally, we need to obtain the market clearing conditions for  $p(X)$  and  $q(X, X')$ , which is done in the following section.

## 4.2 Market Prices and Bank Profits

**Resale-market Price Function.** The linearity of policy functions allows for aggregation. Integrating across the measure of c-producer's capital stock yields their aggregate demand for following-period capital:

$$D^c(X, X') = \left[ \frac{\beta(A + q(X, X')\bar{\lambda}(\phi'))}{q(X, X')} - \bar{\lambda}(\phi') \right] (1 - \pi)K.$$

The demand for capital units by k-producers is obtained similarly. In this case, their aggregate demand function is broken up into three tranches because  $q$  determines whether they buy capital or produce it:<sup>31</sup>

$$D^k(X, X') = \begin{cases} \beta \frac{p(X)\omega^*(X)}{q(X, X')} & \text{if } q(X, X') < 1 \\ [0, \beta p(X)\omega^*(X)\pi K] & \text{if } q(X, X') = 1 \\ 0 & \text{if } q(X, X') > 1. \end{cases}$$

Aggregate investment is the difference between the k-producer's desired capital holdings and their demand for units sold by banks:<sup>32</sup>

$$I(X, X') = \beta \frac{p(X)\omega^*(X)}{q(X, X')} \pi K - D^k(X, X').$$

Capital supplied by bankers during the second stage,  $S(X, X')$ , are the units sold by k-producers during the first stage scaled by their average quality:

$$S(X, X') = \mathbb{E}[\lambda(\omega, \phi') | \omega < \omega^*(X)] \omega^*(X) \pi K.$$

$q(X, X')$  is obtained by using these expressions, and clearing out the price from the second-stage market-clearing equation. This price is characterized by:<sup>33</sup>

<sup>31</sup>The first tranche is downwards sloping when  $q < 1$ . This is a region for values of  $q$  in which k-producers find it cheaper to buy capital than to produce it. The second region is a flat demand at  $q = 1$  since k-producers are indifferent between investing or buying capital. Otherwise, k-producers do not participate in the market when  $q > 1$  because it is less costly to produce capital directly.

<sup>32</sup>From the expression, it is clear that investment is 0 when  $q < 1$ . When  $q = 1$ ,  $D^k(X, X')$  is obtained as the residual of the difference between the supply of used units minus purchases by k-producers.

<sup>33</sup> $q(X, X')$  depends not only on the second stage state  $X'$  but also on  $X$ . The dependence on  $X$  is because the supply of capital

**Proposition 6** *In equilibrium  $q$  is given by,*

$$q(X, X') = \max \left\{ \left[ \frac{\beta A}{\pi \omega^*(X) \mathbb{E}[\lambda(\omega, \phi') | \omega < \omega^*(X)] + (1 - \pi)(1 - \beta) \bar{\lambda}(\phi')} \right], g(p(X), X') \right\}$$

where

$$g(p(X), X') \equiv \min \left\{ 1, \frac{\beta(\pi p(X) \omega^*(X) + A(1 - \pi))}{(\beta \omega^*(X) \mathbb{E}[\lambda(\omega, \phi') | \omega < \omega^*(X)] \pi + (1 - \beta) \bar{\lambda}(\phi'))} \right\}.$$

There are two things worth noting about this price function. First, it is immediate to show that it is decreasing in  $\omega^*(X)$ . This is a natural outcome since larger cut offs lead to more capital supplied by banks (and capital is a normal good). Secondly, the price is decreasing in  $\phi$ . This shock lowers the average quality of capital for any possible cut-off, which is equivalent to lowering the supply of this good.<sup>34</sup>

**Pooling-market Price Function.** In equilibrium, market clearing in the first stage requires:

$$Q^*(X) \int_0^\infty n'(n, X) d\Lambda(n) = \omega^*(X) \int_0^\infty k \Gamma^k(dk) \iff Q^*(X) \kappa = \omega^*(X).$$

Note that  $p(X)$  determines  $\omega^*(X)$  through the k-producer's portfolio problem, which is independent of the capital stock. This is the reason why equilibria only depend on  $\kappa$  and not on the relative wealth of either sector. Conversely, any given pooling price  $p^*$  can be solved implicitly as a function of any  $\omega^*$  through the k-producer's portfolio problem. To obtain the actual price in a given state, one must find the largest possible  $\omega^*$  for which the current  $\kappa$  can sustain losses at such levels of intermediation. Such  $\omega^*$  determines  $p(X)$ . The following proposition shows that  $p$  is well defined and monotone in the size of the financial sector.

**Proposition 7** *Given a state  $X$  and a law of motion for the state, there exists some  $p(X)$  satisfying market clearing. In addition, in any Pareto un-improvable equilibrium,  $p(X)$  is weakly increasing, and right continuous in the financial risk capacity  $\kappa$ .*

This result implies that the volume of intermediation is greater when the financial risk capacity is higher. In turn,  $\kappa$  is determined by the bankers' financial decisions that ultimately depend on expected returns.

**Bank Profits.** Replacing the functional form  $q$  obtained in Proposition 6, we find an analytic expression for marginal profits:

$$\Pi(X, X') = \begin{cases} \frac{\beta(\pi p(X) \omega^*(X) + A(1 - \pi))}{\beta \omega^*(X) \pi + (1 - \beta) \frac{\bar{\lambda}(\phi')}{\mathbb{E}[\lambda(\omega, \phi') | \omega < \omega^*(X)]}} - p(\omega^*(X)) & \text{if } q(X, X') < 1 \\ \mathbb{E}[\lambda(\omega, \phi') | \omega < \omega^*(X)] - p(\omega^*(X)) & \text{if } q(X, X') = 1 \\ \frac{\beta A}{\pi \omega^*(X) + (1 - \pi)(1 - \beta) \frac{\bar{\lambda}(\phi')}{\mathbb{E}[\lambda(\omega, \phi') | \omega < \omega^*(X)]}} - p(\omega^*(X)) & \text{if } q(X, X') > 1 \end{cases}$$

Recall that  $p(X)$  is determined prior to the realization of  $\phi'$  so this price does not respond to  $\phi'$ . One can observe that  $\Pi(X, X')$  is decreasing in  $\phi'$  because, for any possible  $\omega^*(X)$ ,  $\mathbb{E}[\lambda(\omega, \phi') | \omega < \omega^*(X)]$  is decreasing in the shock. Thus,  $\phi'$  affects marginal profits on two dimensions. The first is on the quantity dimension since there is a contraction in the supply of following period capital induced by a greater depreciation. The second is the positive effect in price,  $q(X, X')$ , caused by the reduction in the supply. Marginal

is a function of the cut-off function  $\omega^*(X)$ , which is decided in the prior stage. This price may also depend on  $p(X)$  because this determines the wealth of k-producers who, in turn, purchase capital when  $q(X, X') < 1$ .

<sup>34</sup>The response of  $q$  to  $\phi$  is also a measure of the inefficiencies that occur in this economy. The social cost of investment is 1. A larger  $\phi$  increases the market price of capital beyond its social cost. The wedge between  $q$  and 1 is a measure of ex-post inefficiency.

profits decrease because the first effect always dominates since capital is a normal good. Thus, larger  $\phi'$  are associated with worse results for the banking industry. In contrast,  $\Pi(X, X')$  is not monotone in  $\kappa$ . This is the main feature that determines the evolution of  $\kappa$  and, consequently, the dynamics of this economy.

**Why are bank returns non-monotone?** From Proposition 7 we know that  $p(X)$  is increasing in  $\kappa$ . Hence, non-monotonicity must follow from the value of the capital pool,  $q(X, X') \mathbb{E}[\lambda(\omega, \phi') | \omega < \omega^*(X)]$ . The reason for this non-monotonicity is that two effects oppose each other as the volume of intermediation increases. On one hand, there is a quantity effect: Since capital is a normal good, the greater the volume of capital supplied, the lower its price  $q(X, X')$ . However, the value of the capital pool is also affected by its quality. Thus, on the other hand, as the volume  $\omega^*(X)$  increases with  $\kappa$ , so does its average quality. The two effects interact in a way that marginal profits are non-monotonic if  $\lambda(\omega, \phi)$  is sufficiently sensitive to  $\omega$ . The non-monotonicity of profits in  $\kappa$  also makes  $\tilde{v}(X)$ , non-monotone. This is ultimately the critical factor that prevents the recapitalization of the financial system in times of low  $\kappa$ .

As explained earlier,  $q(X, X')$  is decreasing in  $\kappa$  regardless of the state. This feature implies that if  $\lambda(\omega, \phi)$  is constant across qualities, that is, if asymmetric information is not present,  $\mathbb{E}[\lambda(\omega, \phi') | \omega > \omega^*(X)]$  is constant. Hence, marginal profits are decreasing in  $\kappa$ . This discussion proves the following proposition.

**Proposition 8** *Without asymmetric information, marginal profits  $\Pi(X, X')$  are decreasing in the financial risk capacity  $\kappa$ . For sufficiently severe asymmetric information  $\Pi(X, X')$ , is non-monotone.*

### 4.3 Evolution of Financial Risk Capacity

**Equity Injections and Dividends.** In equilibrium,  $\tilde{v}(X) \in [(1 - \tau), 1]$  for any  $X$ . If it were the case that  $\tilde{v}(X) > 1$  for a given  $X$ , equity would be injected into the banking system until the value of equity is one. This always happens because, eventually, competition effects dominate quality effects when  $\kappa$  is increased. If this did not happen, bankers would have incentives to alter the financial composition of their banks. In turn, this would imply that  $\kappa$  is not in equilibrium. Hence, states where  $\tilde{v}(X) > 1$  are instantaneously reflected into a new state where  $\tilde{v}(A \times \phi \times \kappa') = 1$  for some  $\kappa' > \kappa$ .

The opposite occurs when  $\tilde{v}(X) < (1 - \tau)$ . In such states, dividends are paid until  $\tilde{v}(X) = (1 - \tau)$ . This means that there is an inaction region characterized by states where  $\tilde{v}(X) \in [1 - \tau, 1]$ . Thus, at the beginning of the first stage,  $\kappa$  evolves according to:

$$\kappa' = (1 + e^*(X) - d^*(X)) \kappa. \quad (7)$$

**Multiplicity of Financial Policies and Equilibrium Selection.** Notice that equation (7) is implicit in  $\kappa'$  since  $\kappa' \in X$ . Proposition 5 imposes constraints on the set of equilibrium  $\kappa'$ . But since a banker's decisions are in principle functions of other banker's decisions, there are multiple equity injection policies consistent with equilibrium. For the rest of the paper, I use a refinement and refer to this outcome as the equilibrium. I will select an equilibrium that depends on  $\kappa$ . That is, if  $\tilde{v}(A \times \phi \times \kappa) \in [(1 - \tau), 1]$ , then  $e^*(X) = d^*(X) = 0$ . That is, I will use equilibria such that if the state is in a possible equilibrium, that equilibrium is then selected.

Accordingly, if  $\tilde{v}(A \times \phi \times \kappa) > 1$ , I will select equilibria for which  $e^*(X)$  takes  $\kappa'$  to the closest value above  $\kappa$  such that  $\tilde{v}(A \times \phi \times \kappa) = 1$ . Analogously, if  $\tilde{v}(A \times \phi \times \kappa) < (1 - \tau)$ , then  $d^*(X)$  takes  $\kappa'$  to the closest value below  $\kappa$  such that  $\tilde{v}(A \times \phi \times \kappa) = 1$ .

I have two reasons to select this equilibrium. First, this equilibrium delivers persistent declines in output. Second, in this paper, I assumed that  $\bar{e}$  is never binding to simplify the solution and to argue that bankers may fail to inject equity in spite of resources being available. However, if  $\bar{e}$  is binding, it could be the case that it is insufficient to take  $\kappa'$  to a point where  $\tilde{v}(X) \geq 1$ . If this is the case, other equilibria where equity injections occur could disappear.

**Second -Stage Evolution.** Between the first and the second stages,  $\kappa$  evolves depending on realized profits and the growth rate of the capital stock:

$$\kappa' = R^b [1 + \Pi(X, X') Q^*(X)] \frac{\kappa}{\gamma(X, X')}.$$

In this expression,  $\gamma(X, X')$  is the growth rate of the capital stock:

$$\gamma(X, X') = \pi \beta \frac{[p(X) \omega^*(X) + q^c(X, X') \mathbb{E}[\lambda(\omega, \phi') | \omega > \omega^*(X)] \omega^*(X)]}{q^c(X, X')} + (1 - \pi) \beta \frac{[A + q(X, X') \bar{\lambda}(\phi)]}{q(X, X')}$$

**Marginal Equity Value Functional Equation.** We can obtain a recursive expression for  $\tilde{v}(X)$  and  $v_1^f(X)$  that depend on the transition function from  $X$  to  $X''$  by evaluating the Bellman equation at the optimal policies. The marginal value of bank equity at any state  $X$  is:

$$v_1^f(X) = \min \left\{ \max \left\{ \beta^f R^b \mathbb{E}[\tilde{v}(X) | X], (1 - \tau) \right\}, 1 \right\}. \quad (8)$$

Combining this expression with the definitions of  $\tilde{v}(X)$  and  $v_2^f(X)$  defines a self-map for  $v_1^f(X)$ .<sup>35</sup> In any RCE, the state space may be divided into several regions depending on the shape of  $\tilde{v}$ . The following section describes the possible states of the financial industry.

#### 4.4 States of the Financial Industry

The states of the financial industry are defined in terms of the incentives to inject equity or pay dividends. These policies affect the volume of intermediation by increasing or decreasing the financial risk capacity. For a given exogenous state,  $(A, \phi)$ , these are summarized by the marginal value of equity and how it changes with  $\kappa$ . Thus, the state space can be separated into 4 regions depending on  $\tilde{v}(X)$  and  $\tilde{v}_\kappa(X)$ . At a given state  $X$  equity injections or dividends can instantaneously change  $\kappa$  that, in turn, alters  $\tilde{v}(X)$  and  $\tilde{v}_\kappa(X)$ . Since this analysis is static, the following description leaves  $(A, \phi)$  fixed.

**Dividend-Payoff and Reflecting Barrier.** As explained earlier, dividends are paid whenever  $\tilde{v}(X) < (1 - \tau)$ . When  $\kappa$  falls within this region, dividends payments instantaneously reduce  $\kappa$  to its closest reflecting barrier: The closest  $\kappa$  satisfying  $\tilde{v}(X) = (1 - \tau)$ . A dividend-payoff region associated with a sufficiently large  $\kappa$  always exists. This is because expected profits must be decreasing for large enough  $\omega^*$ .<sup>36</sup> In equilibrium, expected profits are positive, so  $\kappa$  enters this region infinitely often. There may be dividend-payoff regions for intermediate values of  $\kappa$  if the quality effect brings down marginal profits at those levels.

**Equity-Injection and Reflecting Barrier.** When  $\kappa$  falls in states where  $v(X) > 1$ , expected discounted profits are high enough to attract equity injections. Injections reflect  $\kappa$  to the closest point satisfying  $v(X) = 1$ ,

<sup>35</sup>Blackwell's conditions cannot be checked immediately because it may fail to satisfy the discounting property. The operator is monotone, though. All numerical iterations lead to the same outcome. When  $\rho = 1$ , analytical expressions can be obtained.

<sup>36</sup>This occurs because the quantity effect always dominates the quality effect as  $\omega^*$  approaches 1 because volumes have less impact on the conditional expectation at the end of the support. As argued earlier,  $\omega$  is also increasing  $\kappa$ .

so this region is the counterpart of the dividend pay-off region. Similarly, there may also be multiple intervals of  $\kappa$  with this property.

**Competitive Inaction Regime.** The other two possible regions correspond to inaction regions. These can be subdivided into two. The first is a competitive inaction region:

**Definition 3** (Competitive Inaction Region) *A state  $X$  is in a competitive inaction region if (a)  $\tilde{v}(X) \in [(1 - \tau), 1]$  and (b) when  $v_\kappa(X)$  exists,  $v_\kappa(X) \leq 0$  and, if defined,  $v_\kappa(X)|_{\tilde{\kappa}} \leq 0$  for any  $\tilde{\kappa} > \kappa$ .*

Condition (a) guarantees this is an inaction region. Condition (b) implies that expected discounted marginal profits are decreasing in the financial risk capacity for small increases from a given level of  $\kappa$  onwards. This implies that there are less incentives to recapitalize banks as the financial risk capacity increases. In equilibrium  $\tilde{v}(X)$  may jump as a consequence of the Pareto refinement. For this reason, condition (b) is not equivalent to  $v(X)$  being decreasing. Instead, the condition says that it is decreasing from that level of  $\kappa$  onwards, except at the finitely many points where the Pareto refinement applies. This definition captures the idea that the quantity effect dominates the quality (adverse selection) in a competitive inaction region. Therefore, expected discounted profits decrease with more intermediation. Although a Pareto refinement may change these incentives at a given point, it does not modify the direction of these incentives in the vicinity of that point. I label this region as competitive because it is consistent with competition arguments by which marginal profits are decreasing in the volume. We can say more, in fact,

**Proposition 9** *Every equilibrium has a competitive inaction region. Moreover, the inaction region with the largest volumes of intermediation is always competitive.*

**Financial Crisis (inaction) Regime.** The remaining region is the financial crises regime. It is defined by,

**Definition 4** (Financial Crises Region) *A state  $X$  is in a financial crises region if (a)  $\tilde{v}(X) \in [(1 - \tau), 1]$  and is not a competitive inaction region.*

In a financial crises regime,  $\kappa$  is low in the sense that it triggers adverse selection, since banks do not have the net worth to expose themselves to large losses. With low volumes of intermediation, market clearing requires a low  $p(X)$ , but this also brings down the quality of capital traded. Moreover, expected profits are low, and this discourages equity injections. By definition, higher levels of  $\kappa$  increase the value equity in this region. This happens as more financial risk capacity leads to more intermediation, ameliorates adverse selection, and increases expected profits altogether. However, in these region, bankers choose not to recapitalize because they lack the incentives at this level of marginal profits. The situation could be more dramatic: It is possible that at higher levels of  $\kappa$ , expected profits attract equity injections. This means bankers face a coordination problem. If they would all inject equity for higher levels of  $\kappa$ , they would benefit from injecting equity in a financial crisis regime. After all, injections drive  $\tilde{v}(X)$  to 1, a value that is higher than in a financial crisis. However, when profits are low, bankers fail to synchronize over the recapitalization that would end the financial crisis.

Financial crises are therefore regions characterized by low  $\omega^*$  and expected profits. Hence, exit times out of these regions may be long. This feature may cause a feedback by depressing the return to equity even more.

**Efficient Intermediation.** For the policy discussions to come, it is useful to define what is the efficient level of intermediation. A planner facing the same information constraints but without the LLC would purchase capital so that expected profits are zero in every period. To be precise,

**Definition 5** (Efficient Intermediation) *The volume of intermediation in state  $X$  is efficient if it is the largest volume such that  $\mathbb{E}[\Pi(X', X) | X] = 0$ .*

The economy described above may also have states in which intermediation is efficient. There are some conditions required for the occurrence of efficient states.

**Proposition 10** *If  $(1 - \tau) > \beta^F R^b$ , intermediation is never efficient. States with efficient intermediation may occur if  $\beta^F R^b$  is sufficiently close to 1.*

A natural conjecture is that a planner facing the LLC would try to be as close as possible to the efficient levels of intermediation through time. For this purpose, governments may want to impose several government policies. I return to this point in a later section. The following section explains how to compute equilibria.

## 4.5 Solving Equilibria

This section outlines the strategy to compute Pareto un-improvable equilibria. The solution method involves two steps. The first is to compute first- and second- stage prices and expected profits for any (possibly off-equilibrium) volume of intermediation given exogenous states  $(A, \phi, \phi')$ . The second step uses these calculations to find equilibrium volumes given  $\kappa$  and with this, obtain  $\tilde{v}(X)$ , and the inaction regions for  $\kappa$ .

**Notation.** Equilibrium objects are functions of the aggregate state. However, to compute equilibria, one needs to obtain prices and profits for any off-equilibrium  $\omega$ . I use bold letters to distinguish equilibrium from non-equilibrium objects. Thus, I use  $\mathbf{p}(\omega, \phi)$  to indicate the first-stage supply schedule given  $\phi$  and a value of  $\omega$ . In addition,  $\mathbf{q}(\omega, \mathbf{p}, A, \phi')$  denotes the price consistent with second-stage market clearing given  $(\omega, \mathbf{p}, A, \phi')$ . Finally,  $\mathbf{\Pi}(\omega, \mathbf{p}, A, \phi')$  are the corresponding profits given these prices, volumes, and exogenous states.

**Step 1: Volumes, Prices, and Profits off equilibrium.** Through Proposition 3, we can find a first-stage price  $\mathbf{p}(\omega, \phi)$  associated with  $\omega$  by inverting the solution to the k-producer's portfolio problem. We can also use Proposition 6 to obtain  $\mathbf{q}(\omega, \mathbf{p}, A, \phi')$  for any pair  $(\omega, \mathbf{p}, A, \phi')$ . With this, we can compute  $\mathbf{\Pi}(\omega, \mathbf{p}, A, \phi')$ , including worst-case losses. These calculations are performed only once.

**Step 2.1: Volumes, Prices, and Profits at equilibrium.** We begin with an initial guess for the marginal value for bank equity  $\tilde{v}(X)$ . This value is updated in the following step. Using the calculations in Step 1, we find the equilibrium volume of intermediation given this guess. Thus, for each  $X$ , we look for the volumes yielding non-negative expected discounted profits and the largest  $\omega$  such that the worst-case losses are at most  $\kappa$ :

$$\omega^*(X) = \max \left( \omega : \kappa \leq \min_{\phi} \mathbf{\Pi}(\omega, \mathbf{p}, A, \phi') \omega \text{ and } \mathbb{E}[\tilde{v}(X') \mathbf{\Pi}(\omega, \mathbf{p}, A, \phi') | X] \geq 0 \right).$$

Since  $\mathbf{\Pi}(\omega, \mathbf{p}, A, \phi')$  is continuous and  $\omega \in [0, 1]$ , this quantity is well defined.  $\omega^*(X)$  is the largest volume of intermediation yielding non-negative expected profits such that there is enough capacity to sustain losses in the worst state. Thus,  $\omega^*(X)$  is consistent with the banker's problem and is the Pareto un-improvable equilibrium volume, the largest volume satisfying market clearing and optimal decisions by all agents.

**Step 2.2: Equilibrium  $\tilde{v}(X)$ .** Given this  $\omega^*(X)$ , one can compute  $\Pi(X, X') = \mathbf{\Pi}(\omega^*(X), \mathbf{p}(\omega^*(X), \phi), A, \phi')$ . We use the functional equation (8) and the definition of  $v_1^f(X)$  to update  $\tilde{v}(X)$ . Steps 2.1 and 2.2 are iterated until convergence. When  $\rho = 1$ ,  $v_2^f(X) = (1 - \tau)$ , so steps 2.1 and 2.2 are done only once. Appendix A provides details for the implementation of this strategy in a computer. The following section describes two



examples of equilibria to compare economies with and without asymmetric information. In doing so, these examples illustrate the solution method.

## 5 Analytic Examples

This section provides two examples that illustrate how equity injections and dividends are stabilizing forces for this economy. The first describes a version of the model under symmetric information. The second example contrasts this with a version in which asymmetric information is severe. The point of the section is to show that in presence of severe asymmetric information, recapitalization no longer stabilizes financial markets in response to large shocks. For the rest of this section, I assume  $\rho = 1$  to exploit closed analytic expressions.

### 5.1 Example 1 - Risky intermediation without asymmetric information.

The first example is an economy where financial intermediation is risky but asymmetric information is not present. Here, I assume that  $\lambda(\omega, \phi) = \lambda^*(\phi)$ , so all units are of the same quality but decreasing in  $\phi$ . As explained earlier, this case corresponds to a version of the model with an aggregate depreciation shock  $\bar{\lambda}(\phi')$ . Here,  $\phi$  takes one of two possible values: a good value  $\phi_G$ , and a bad value  $\phi_B$ . Draws are i.i.d. and  $\phi_B > \phi_G$ . In addition,  $A$  is constant. In this environment, we have the following:

**Proposition 11** *In any economy without asymmetric information,  $\kappa'$  fluctuates within a unique equilibrium interval  $[\underline{\kappa}, \bar{\kappa}]$ . If  $\kappa \leq \underline{\kappa}$ , then  $e^*(X)$  is such that  $\kappa' = \underline{\kappa}$ . If  $\kappa \geq \bar{\kappa}$ ,  $d^*(X)$  is such that  $\kappa' = \bar{\kappa}$ .  $v(X)$  is decreasing and  $\omega(X)$  is increasing in  $\kappa$ .*

The proof to this proposition is straight forward. From Proposition 6, we know that  $\Pi(\omega, \mathbf{p}, \phi)$  is decreasing in  $\omega$  since quality effects are not present without asymmetric information. Also, as noted earlier,  $\rho = 1$ ,  $v_2^f(X) = (1 - \tau)$ . We can use  $\Pi(\omega, \mathbf{p}, \phi)$  and equation (6) to obtain an expression for the marginal value of equity in terms of any arbitrary  $\omega$ . Call that value  $\tilde{\mathbf{v}}(\omega, \mathbf{p})$ . Without asymmetric information,  $\tilde{\mathbf{v}}(\omega, \mathbf{p}, A, \phi)$  is decreasing in  $\omega$ . Consequently, by Propositions 5, there is a unique interval for  $\omega$  such that  $\tilde{\mathbf{v}}(\omega, \mathbf{p}) \in [(1 - \tau), 1]$ . Correspondingly, since  $\Pi$  is decreasing in  $\omega$ , there is a unique equilibrium interval for  $\kappa$  that determines a unique competitive inaction region.

Figure 3 shows the construction of equilibria graphically. The upper-left panel depicts four curves associated with any arbitrary off-equilibrium  $\omega$ . These correspond to the capital-supply schedule,  $\mathbf{p}(\omega, \phi)$ , the marginal value of bank assets in good and bad states,  $\mathbf{q}(\omega, \mathbf{p}, \phi_H) \lambda^*(\phi_H)$  and  $\mathbf{q}(\omega, \mathbf{p}, \phi_L) \lambda^*(\phi_L)$ , and their expected value  $\mathbb{E}[\mathbf{q}(\omega, \mathbf{p}, \phi) \lambda^*(\phi)]$ . The difference between  $\mathbb{E}[\mathbf{q}(\omega, \mathbf{p}, \phi) \lambda^*(\phi)]$  and  $\mathbf{p}(\omega)$  is the expected marginal profit from financial intermediation. Multiplying this amount by  $\omega$  yields the total expected bank profits  $\mathbb{E}[\mathbf{q}(\omega, \mathbf{p}, \phi) \lambda^*(\phi) - \mathbf{p}(\omega)]\omega$  normalized by the capital stock. Total expected bank profits are plotted at the bottom-left panel. The bottom-right panel plots worst-case profits,  $[\mathbf{q}(\omega, \mathbf{p}, \phi_L) \lambda^*(\phi_L) - \mathbf{p}(\omega)]\omega$ , also normalized. In equilibrium,  $\kappa$  must be sufficient to sustain the losses induced by a volume of intermediation associated with it. The panel in the top right plots the expected value of bank equity  $\tilde{\mathbf{v}}(\omega, \mathbf{p})$  as a function of  $\omega$ .

The horizontal lines in the top-right panel are the marginal costs of injecting equity and the marginal benefit of dividend pay-offs, 1 and  $(1 - \tau)$ , respectively. In equilibrium, if a given  $\omega$  is the equilibrium volume of intermediation, bankers will not alter the net worth of their banks at that volume of intermediation. The set of possible equilibrium  $\omega$  is characterized by volumes for which the value of equity is within the marginal

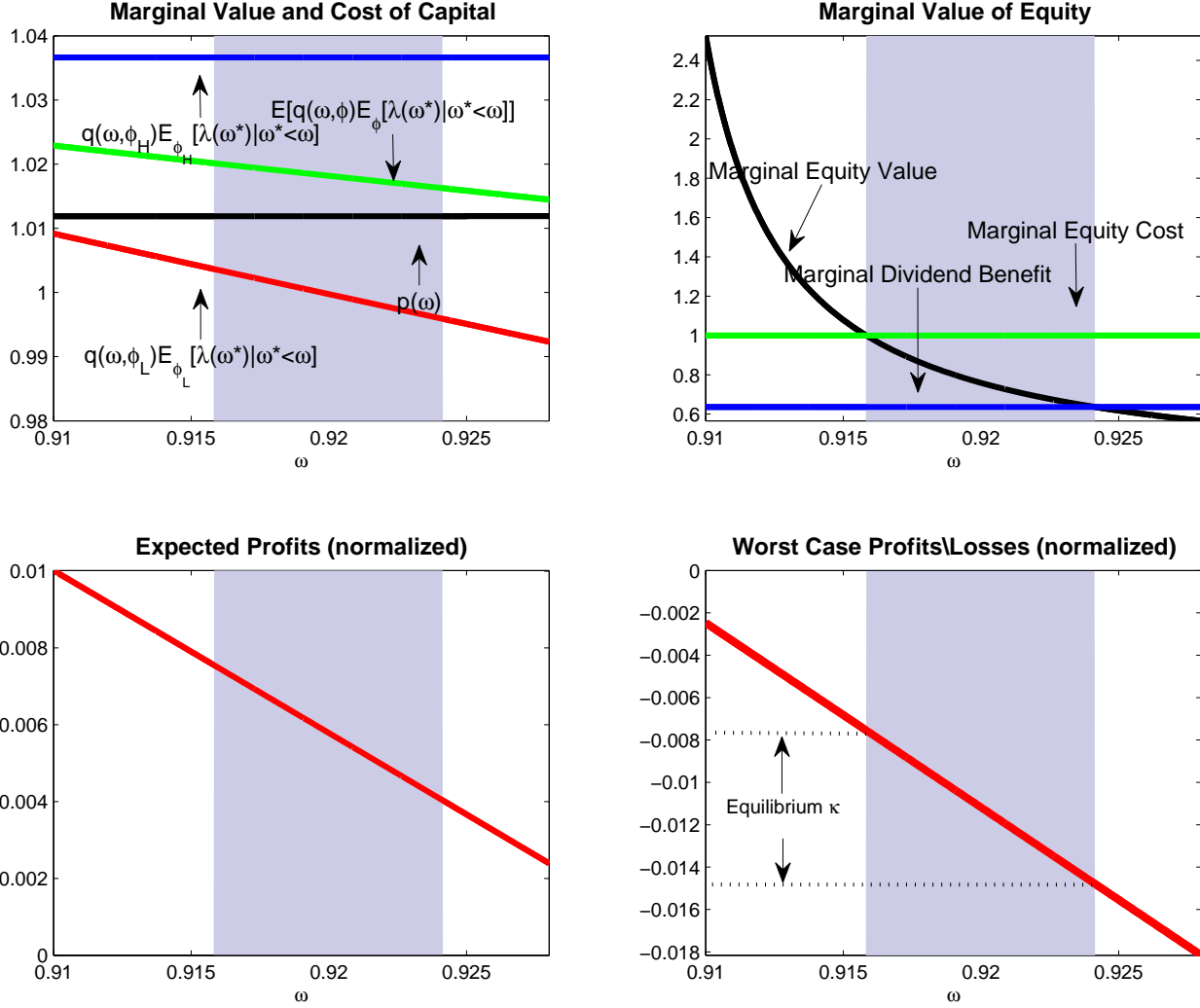


Figure 3: **Model without asymmetric information: Equilibrium objects as functions of  $\omega$ .** Parameters are set to:  $\pi = 0.1$ ,  $\beta = 0.99$ ,  $\beta^f = 0.99$ ,  $A = 1.42$ ,  $\tau = 0.6364$ ,  $\rho = 1$ .

cost of injections and the benefit of dividend payouts. The shaded areas in the graphs correspond to this set. Since,  $\tilde{\mathbf{v}}(\omega, \mathbf{p})$  is decreasing in  $\omega$ , the equilibrium set is a unique interval. For each  $\omega$  in that interval, there is an equilibrium  $\kappa$  corresponding to it. Following step 2 in the previous section, we obtain this equilibrium set by computing the maximal losses given each  $\omega$  in the equilibrium set. The bottom-right panel shows this interval for  $\kappa$  is obtained as the image of worst-case losses for the equilibrium  $\omega$ -set.

Figure 4 plots the equilibrium objects. These are obtained by following the second step of the solution method described earlier. The top-left panel plots  $\omega^*$  as a function of  $\kappa$  (that is,  $\kappa$  before equity injections or dividends). The panel on the top right depicts  $\tilde{v}$ . In equilibrium,  $\kappa'$  must be in the inaction region where  $\tilde{v}(\kappa) \in [(1 - \tau), 1]$ . The bottom panel depicts equity injections, dividends and  $\kappa'$  as functions of  $\kappa$ . In equilibrium,  $e$  and  $d$  adjust to bring  $\kappa'$  to the equilibrium set depicted in Figure 3. The shaded area in the figure is the competitive inaction region. The regions to the right and left of the shaded area are the dividend payoff and equity injection regions, respectively.

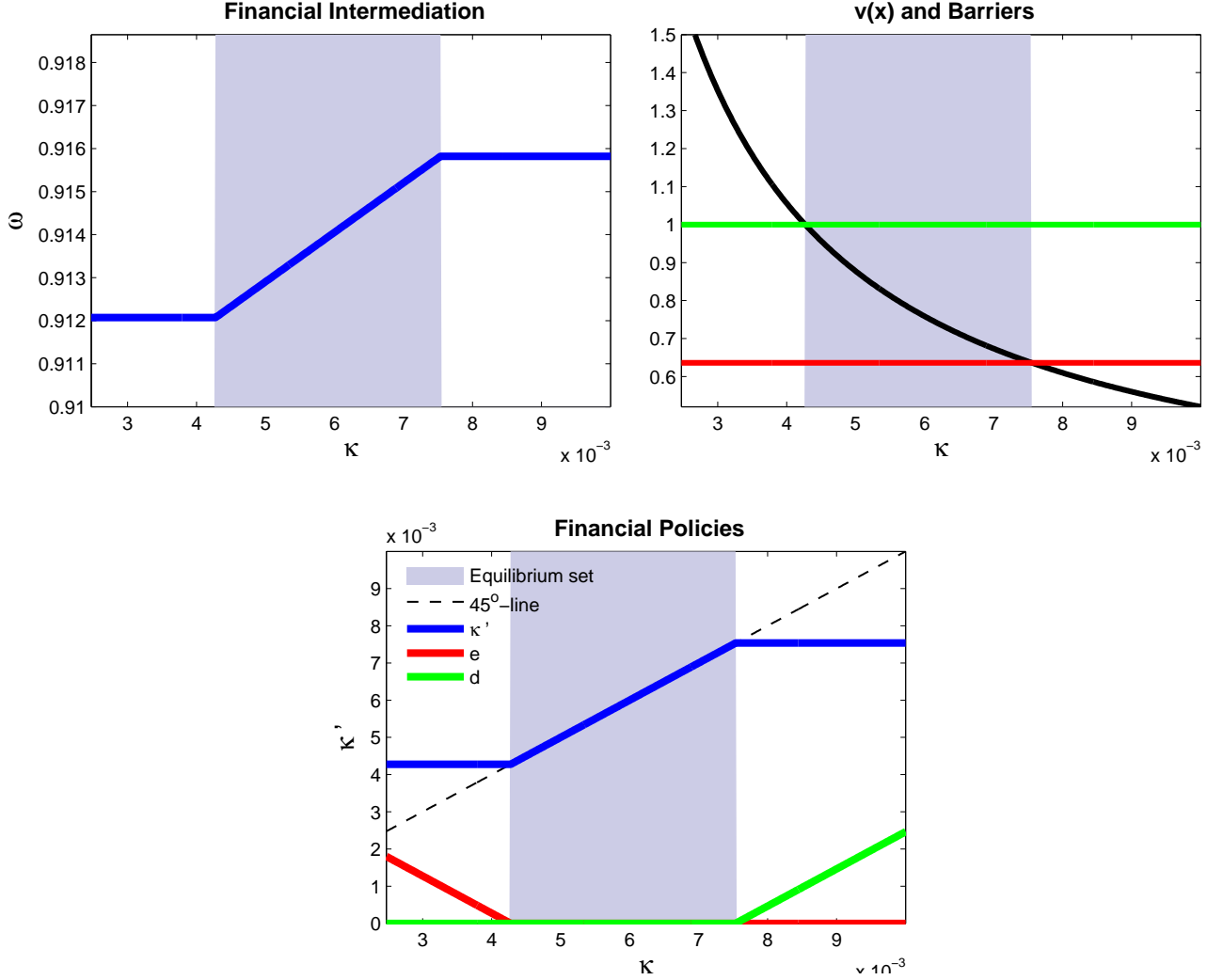


Figure 4: **Model without asymmetric information: Equilibrium objects the as functions of  $\kappa$ .**

**Dynamics.** Proposition 11 is useful to understand the dynamics of this economy. Recall that, in equilibrium, worst-case losses are always negative because the converse would imply infinite leverage and infinite expected profits. In contrast, expected profits must be non-negative or, otherwise, no intermediation would be provided. This implies that  $\kappa$  will increase or decrease depending on the realization of  $\phi$ . When  $\phi_B$  is realized, profits are negative and drag  $\kappa$  down. Below  $\underline{\kappa}$ , profits attract equity injections that recapitalize banks and increase the financial risk capacity. Thus, injections stabilize a system with low financial risk capacity. When  $\phi_G$  is realized, dividends work in the opposite direction and  $\kappa$  increases in expectation. When it increases beyond  $\bar{\kappa}$ , dividend payoffs reflect the financial risk capacity downwards. Hence, without asymmetric information,  $\kappa$  fluctuates within a unique interval. The next example shows how asymmetric information changes incentives to inject equity in a way that precludes this stabilizing force.

## 5.2 Example 2 - Risky intermediation with asymmetric information.

I modify  $\lambda(\omega, \phi)$  to introduce asymmetric information by altering the functional form for  $\mathbb{E}[\lambda(\omega, \phi') | \omega < \omega^*]$ . I fix values for the lower and upper bounds of  $\lambda(\omega, \phi)$ ,  $\lambda_L$  and  $\lambda_H$ . Then, I use the following functional form  $\mathbb{E}[\lambda(\omega, \phi) | \omega < \omega^*] = \lambda_L + (\lambda_H - \lambda_L) F_\phi(\omega^*)$ . I assume  $F_\phi$  is the CDF of a Beta distribution where  $\phi$  indexes its parameters in a way that satisfies Assumption 1. The rest of the calibration is similar to the one in the previous example.

Figure 5 is the asymmetric-information analog of Figure 3. The upper-left panel shows four curves that correspond to  $\mathbf{p}(\omega, \phi)$ ,  $\mathbf{q}(\omega, \mathbf{p}, \phi_H) \lambda(\phi_H)$ ,  $\mathbf{q}(\omega, \mathbf{p}, \phi_L) \lambda(\phi_L)$ , and  $\mathbb{E}[\mathbf{q}(\omega, \mathbf{p}, \phi) \lambda(\phi)]$ . Note that  $\mathbf{q}(\omega, \mathbf{p}, \phi_H) \lambda(\phi_H)$  and  $\mathbf{q}(\omega, \mathbf{p}, \phi_L) \lambda(\phi_L)$  are no longer decreasing in  $\omega$  after asymmetric information is introduced. As volumes increase, the price of capital falls, but the quality improves. The relative strength of either effect governs the shape of the value of bank assets. These forces cause total expected and worst-case profits to be non-monotonic (bottom-left and right panels). Same levels of worst-case losses can result from multiple values of  $\omega$ . This implies that a given  $\kappa$  can possibly sustain multiple levels of intermediation. The Pareto refinement implies that, in equilibrium, the largest volume consistent with bank optimality and the capacity constraint is intermediated. The top-right panel plots the marginal value of bank equity. There is an important difference in the shape of the value of bank equity when asymmetric information is present. With asymmetric information, the marginal value of equity inherits the non-monotonic behavior of profits. Once again, the horizontal lines correspond to the marginal cost equity and benefit of dividends. Non-monotonic profits lead to multiple inaction regions. In particular, for low levels of intermediation, expected profits are low and equity injections are not profitable.

This example also illustrates the wide range of phenomena that may occur when asymmetric information is incorporated. Not surprisingly, this system will have much richer dynamics in this case. For this particular example, there are three equilibrium inaction intervals identified by the shaded areas. As before, each volume in this interval is identified with a single  $\kappa$  that sustain potential losses. Again, the equilibrium intervals for the financial risk capacity are obtained as the image of the worst-case losses for each equilibrium  $\omega$ -interval. The intervals corresponding to the largest sizes of  $\kappa$  (intervals I and II in the figure) are competitive inaction regions.<sup>37</sup> The upper bound of interval II in the figure has a distinctive property: If  $\kappa$  is increased slightly at that point, it can support a much larger level of intermediation. This happens because there is a much larger level of intermediation that only increases worst-case losses infinitesimally. The Pareto refinement will push intermediation towards those levels.

Interval III is a financial crises regime. It is associated with low levels of financial intermediation. This region is an inaction region since bankers do not inject equity at these levels. Note that for larger values of  $\omega$ , equity injections are profitable since  $\tilde{\mathbf{v}}$  is above 1. As discussed earlier, this underscores the nature of the coordination failure faced by banks. Banks choose to keep their net worth low and engage in less intermediation; and by this, only bad quality capital is traded.

Figure 6 plots the equilibrium objects as functions of  $\kappa$ . The upper-left panel plots the equilibrium financial intermediation. We can observe a discrete jump in the volume of intermediation from the second to the first region. This jump is the result of the fact that slightly larger  $\kappa$  can support a much larger volume of intermediation and the Pareto refinement selects the equilibrium with largest volumes. The equity injection

<sup>37</sup>Note that the condition for an inaction competitive regions is with respect to  $\kappa$  and not  $\omega$ . Although  $\mathbf{v}$  is non-monotone for larger values of  $\omega$ , the sign of  $v_\kappa$  does not change for larger values of  $\kappa$ . Had I defined inaction competitive regions in terms of monotonic properties, region II would be a financial crisis region also.

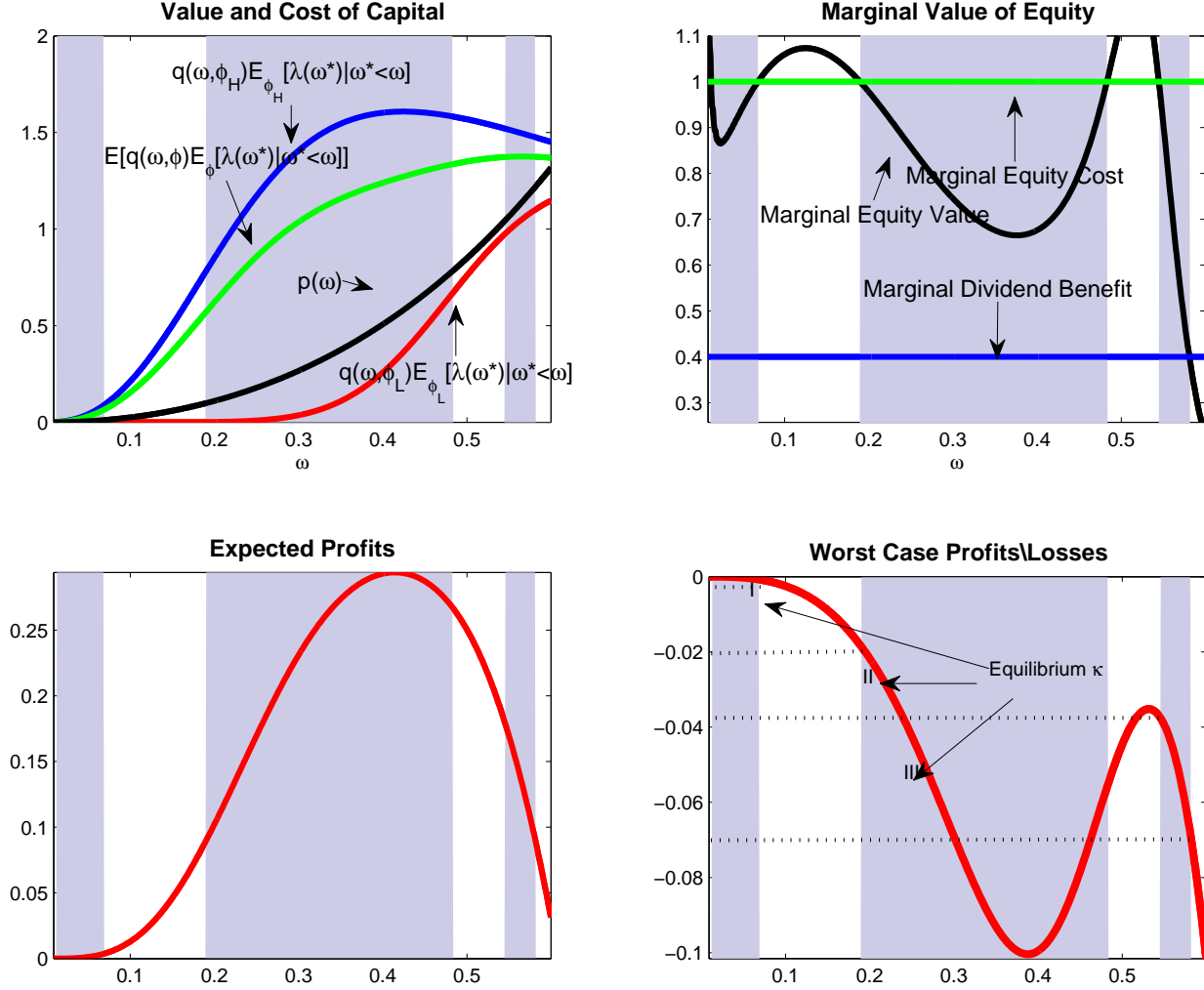


Figure 5: **Model with asymmetric information: Equilibrium objects as functions of  $\omega$ .** Parameters are set to:  $\pi = 0.1$ ,  $\beta = 0.98$ ,  $\beta^f = 0.6$ ,  $A = 1.45$ ,  $\tau = 0.6364$ ,  $\rho = 1$ .

region between regions I and II is very small: regions I and II are close to each other. Note that to the left of the second region, the marginal value of equity  $\tilde{v}$  is increasing for very low values of  $\kappa$ . The financial crisis regime can be barely observed because the volume of intermediation and losses associated with it are very small. Hence,  $\kappa$  is very small in that region. This regime occurs when  $\tilde{v}$  crosses the cost of equity injections. Thus, in presence of asymmetric information,  $e$  and  $d$  may cease to adjust  $\kappa'$  for low values.

Figure 11 in the appendix illustrates equilibrium banking and economic activity indicators as functions of  $\kappa$ . Among other things, the figure shows that the financial crises regime is characterized by lower growth and investment rates. By means of an example, we have shown:

**Proposition 12** *For sufficiently severe asymmetric information, the return to financial intermediation is non-monotone in  $\kappa$  and there exists a financial crises regime.*

**Dynamics.** The immediate effects  $\phi$  on  $\kappa$  are the same as in the version without asymmetric information. However, the dynamics can be very different. With asymmetric information, a realization of  $\phi = \phi_B$  can drive

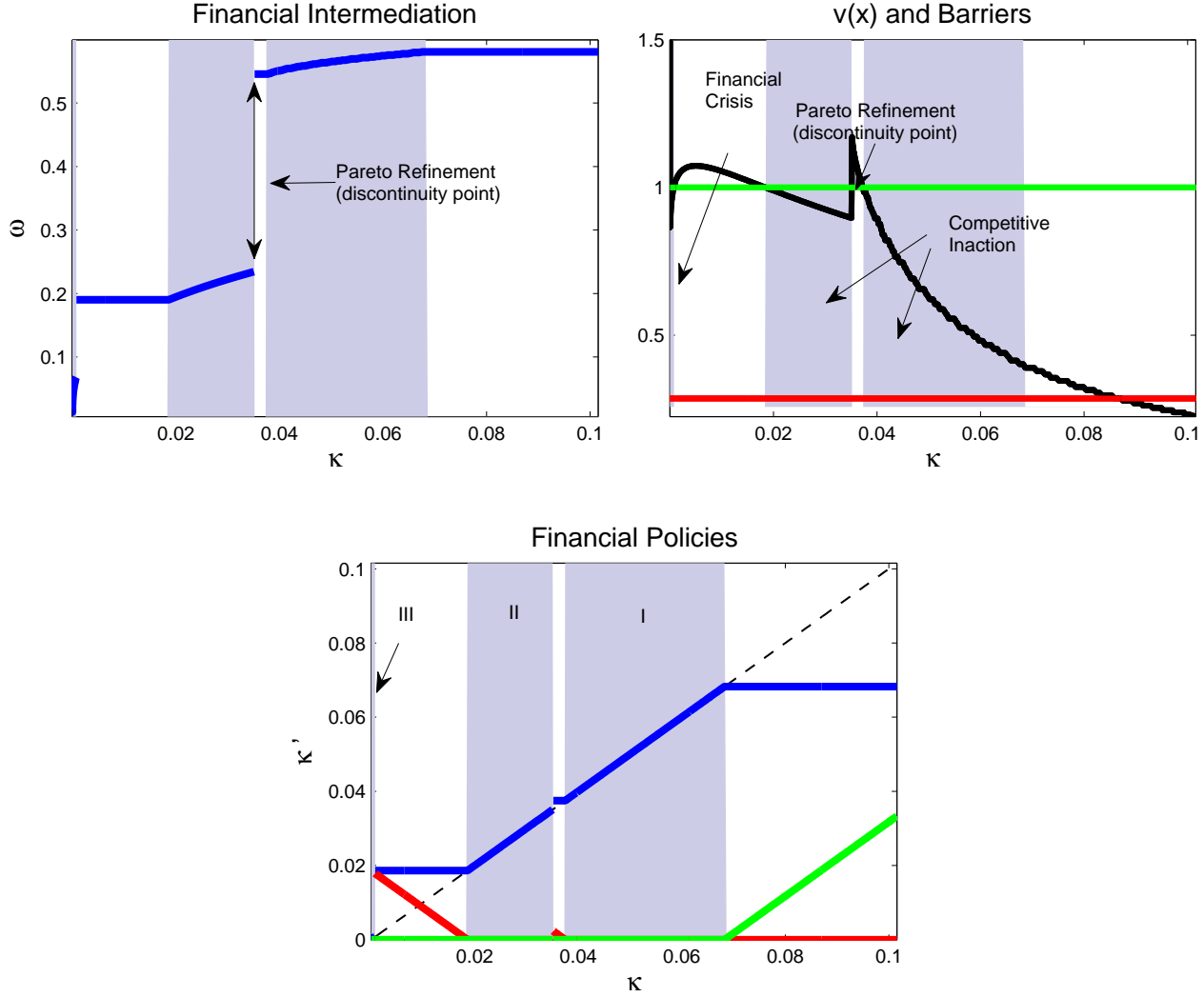


Figure 6: **Model with asymmetric information: Equilibrium objects the as functions of  $\kappa$ .**

the financial system to the financial crises regime. As adverse selection effects are aggravated, profitability no longer justifies the injection of capital into the system, and the economy may take long to recover. The economy eventually recovers as banks slowly build equity through retained earnings. Once  $\kappa$  reaches the equity injection regions between intervals III and II, the banking system attracts equity injections, and  $\kappa$  reaches the competitive inaction region II.

The following section of the paper studies a richer version of this model introducing some extensions. As a preview, and to get a sense of the dynamics just described, Figure 12 presents a sample path of the equilibrium variables from this richer version. The intuition is the same as explained above. The simulations correspond to 80 periods. Periods where the states belongs to a financial crisis are identified by the shaded areas in each plot. The top-left panel describes the evolution of  $\kappa$  and  $\kappa'$ . Most of the time,  $\kappa$  fluctuates between a given band. The middle-left panel plots expected profits and actual profits, which cause the movements in  $\kappa$ . One can observe that expected profits are on average close to zero. Actual profits fluctuate around this quantity. When profits are high,  $\kappa$  exceeds its equilibrium size and dividends are paid out (bottom-left panel). Losses



cause a reduction in  $\kappa$ , which are met with rapid equity injections most of the time (bottom-left panel). These injections are justified by increases in expected profits and the marginal value of equity (middle panel).

In crisis episodes, however, the financial system is reduced and remains with low levels of financial risk capacity and low market capitalization (middle-right panel). Instead of increasing, which happens with small shocks, expected profits fall during a crisis. Financial crises are triggered when the purchase cost of capital exceeds the value of capital (middle-top panel). This happens in parallel to declines in intermediation volumes (top-right panel), which are caused by low financial risk capacity. With less intermediation, the growth rate of the economy (bottom-middle panel) falls in response to less investment, and this induces a break in the trend of output (bottom-right panel).

## 6 Quantitative Examples

### 6.1 Issues with U.S. Bank National Accounts

Several issues must be resolved before confronting the model with banking data. This section describes these challenges and the empirical strategy I undertake to reconstruct several measures of aggregate banking indicators. Details are left for the appendix.

**Accounting procedures, regulatory reform, and M&A activity.** For regulatory purposes, the largest commercial banks in the U.S. are organized into legal institutions called bank holding companies (BHCs).<sup>38</sup> The main assets of BHCs are equity of commercial banks. This detail is important because various banking indicators can be constructed from aggregate or disaggregate balance sheets. The relevance of these indicators depends on the application. For example, BHCs also borrow funds directly and indirectly through the liability of their Commercial Bank subsidiaries.<sup>39</sup> This implies that banking indicators, specifically leverage, differ for the consolidated and individual balance sheets. To build an estimate of the relevant bank leverage for this paper, I consider the consolidated balance sheet of the BHCs. Unfortunately, Flow of Funds does not report consolidated BHC balance sheets. Instead, individual consolidated balance sheet are available, and aggregates must be constructed.<sup>40</sup>

Consolidation issues aside, aggregate banking data has been affected by changes in the regulatory framework. These changes have lead many non-BHCs to become BHCs during the last decade. Moreover, these have promoted a considerable amount of merger and acquisition (M&A) activity within the industry.<sup>41</sup> Unfortunately, aggregate banking time series reported in the Flow of Funds do not adjust for mergers and redefinitions. This leads to spurious increments in various aggregate balance sheet accounts. This issue is particularly problematic after 2008 when many investment banks and finance corporations became BHCs.<sup>42</sup>

**Shadow banking.** BHC take positions not reported on their balance sheets. Nonetheless, these positions may lead to substantial operating losses. For example, banks offer substantial amounts of loan commitments and financial insurance contracts. The majority of the losses suffered by the largest institutions during the

<sup>38</sup>See, for example, [Saunders and Cornett \(2010\)](#).

<sup>39</sup>The typical leverage of a BHC is 1. Liabilities are often obtained indirectly via money markets by issuing short term instruments that are not deposits (e.g., REPO and Commercial paper facilities) or via corporate bond issuances.

<sup>40</sup>One can find though the balance sheet of the consolidated financial sector. Commercial banks and BHC balance sheets are reported individually.

<sup>41</sup>The enactment of the Gramm-Leach-Bliley Act of 1999 allowed commercial banks, investment banks, securities firms, and insurance companies to consolidate as bank-holding companies.

<sup>42</sup>Goldman Sachs, Morgan Stanley, American Express, CIT Group and General Motors Acceptance Corporation successfully converted to bank holding companies. M&A effects include Wells Fargo's acquisition of Wachovia in 2008, the 4th largest bank in the U.S. at the time, and J.P. Morgan's acquisition, Washington Mutual assets.

crisis originated from Special Investment Vehicles and Investment Conduits issuing these derivatives. These vehicles were explicitly or implicitly guaranteed by liquidity or bailout facilities funded by the assets of commercial bank under control of the same parent BHC.<sup>43</sup>

**Equity Measures.** Bank equity typically includes a substantial component of intangible assets, such as goodwill. Intangible assets cannot be easily liquidated upon bankruptcy. Goodwill accounts include items (for example, the bank’s trademark) that have no value outside the firm. In fact, the Basel agreements specify constraints based on tangible equity (common equity - goodwill - positive tax accounts) measures. Tangible equity is not reported by Flow of Funds accounts.<sup>44</sup> The relevance of bank equity measures depends also on the assumptions about the impact of TARP equity injections. TARP injections were in the form of preferred equity. In terms of the model, preferred equity may or may not be interpreted as a perfect substitute to common private equity for relaxing the LLC.<sup>45</sup>

**Cash Reserves.** Banks hold non-negligible amounts of cash and other riskless assets (e.g., treasuries) as part of their portfolio. After the crisis, there has been a large shift towards riskless investments. The model is not explicitly about the role for cash. Therefore, I must take a stance on the role of riskless investments to provide a measure of leverage.<sup>46</sup>

## 6.2 Reconstructing U.S. Bank National Accounts

**Empirical Strategy.** To obtain measures of aggregate banking activity from consolidated balance sheets, I aggregated the consolidated balance sheets of the fifty largest U.S. BHCs between 2000 and 2010. I compare the time series of equity for this group to the historical time series of BHCs reported by the Flow of Funds.<sup>47</sup> Prior to 2008, both series are highly correlated, but the relationship breaks down as large institutions are incorporated into the BHC sector. To obtain an appropriately scaled version of the reconstructed series, I rescale it so that the time series of equity for both groups are roughly the same.<sup>48</sup> I use the same scaling factor to obtain measures of consolidated assets and liabilities not available from Flow of Funds. By doing this, I assume treat leverage as constant across the industry.

To isolate the effect of M&A activity, I adjust the sample by keeping only those BHCs that did not experience any substantial changes. Since the equity size distribution of BHCs is fat tailed, I treat the M&A activity for these institutions as if it were the entire M&A activity of the industry. This isolates an important part of the M&A activity but cannot account for the entire effect of M&A activity. The final sample includes 44 BHSs for which I construct M&A-adjusted banking indicators. The adjusted and non-adjusted series are highly correlated until 2008 also. The difference between them gives a sense of the measurement problem caused by redefinitions and mergers. To isolate the effects of TARP injections, I use institution-specific information on equity injections and extract them to obtain ex-TARP measures for the model’s targets. This

<sup>43</sup> The *Shadow Banking* has been widely documented. See for example, Acharya and Richardson (2010), Pozsar et al. (2010), Gorton (2010), or Saunders and Cornett (2010).

<sup>44</sup> Duffie (2011) argues that this is the right measure to account for bank leverage.

<sup>45</sup> In principle, preferred equity could be seen as subordinated debt that does not act as a buffer to bank losses. See, for example, Duffie (2011).

<sup>46</sup> Keister and McAndrews (2009) present evidence that the increase in cash holdings has been the result of TARP, and that these have had minor effects on the bank lending policies.

<sup>47</sup> Note that if one consolidates the balance sheet of a BHC with its commercial bank subsidiary, the consolidated net-worth is close to that of the parent company so long as the subsidiary has no external owners.

<sup>48</sup> This data is available from FRY-9 filings reported by BHCs. It is available from the Federal Reserve Bank of Chicago and [http://www.chicagofed.org/webpages/banking/financial\\_institution\\_reports/index.cfm](http://www.chicagofed.org/webpages/banking/financial_institution_reports/index.cfm). The list of the top 50 BHCs is described by the National Information Center, Federal Reserve System: <http://www.ffiec.gov/nicpubweb/nicweb/Top50Form.aspx> and it is formatted by the Wharton Research Data Services. In terms of assets, the Top 50 BHCs hold 50% in the entire banking industry.

is, again, a lower estimate.<sup>49</sup>

Figure 7 plots these series. The bottom-right panel of the figure presents the evolution of BHC tangible equity for the sample and the industry aggregate (both with and without TARP injections). One can observe that both series behaved very similarly prior to the crisis. Without controlling for TARP injections, equity increases during the period. The top-left panel shows the behavior of loans for the top 50 banks and the sample that excludes M&A activity. A similar pattern can be observed. Prior to 2008, both series look alike, but due to redefinitions, lending increases for the non-adjusted sample. In contrast, loans reported by commercial banks behave similarly as the adjusted sample.

The top-right panel presents total assets of all commercial banks and that of BHCs in the reconstructed sample and the aggregate non-consolidated assets reported by the flow of funds. These series are reportedly adjusted for M&A activity. One can observe two things from this panel. First, there is an order of magnitude between the consolidated BHC assets and the non-consolidated aggregate time series reported in the Flow of Funds. Second, both time series move together throughout the sample prior to 2008. The fact that the adjusted sample series of BHCs and commercial banks comove implies that off-balance sheet items were close to being in zero net supply within the sample of BHCs. Derivative assets, such as Mortgage Back Securities, are accounted for in the BHC's balance sheet but are not part of the Commercial Banks subsidiary assets. If both series had the same scale, the difference in the two would correspond to the net supply of off-balance-sheet items. The difference in the scale is because I am only using a subsample of all the BHCs. Once the sample series is scaled, both series are very close to each other, which reveals that off-balance-sheet items add to a small fraction of aggregate assets (but not in terms of individual bank assets).

Once one adjusts for M&A activity, one can get an idea of the reduction in bank assets. This understates the effect on intermediation because much of TARP injections were converted into cash reserves that banks have not lent out. The effects on real activity can be understood more clearly from the top-left panel. This panel shows how lending froze immediately at the beginning of the crisis, reversing the constant upward trend that prevailed prior to the crisis. The bottom-left panel presents measures of total equity.

I reconstruct aggregate time series that have a theoretical counterpart in the model using individual balance sheets of the adjusted groups. Table 1 summarizes the equivalence between variables in the model and data time series. Individual balance sheets report total commercial and industrial, real estate, leases, and consumer loans (or the total loans from banks to the private sector). I add these entries and treat this sum as my measure for total loans. I also subtracted goodwill and positive tax accounts from equity to construct a measure of tangible equity.<sup>50</sup> I use information on the difference between equity issuances and dividend payoffs to obtain a measure of net equity injections and dividend payoffs. I use net interest and non-interest income plus expenses (salaries, for instance) to compute bank profits and fixed expenses. I can obtain all the moments I am looking for from these measures.

### 6.3 Additional Features

To obtain a better quantitative performance of the model, I incorporate additional features that do not alter its qualitative behavior.

**Financial Management Costs.** Bank returns are influenced by various non-interest expenditures. Most

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<sup>49</sup>The details of TARP are available at: <http://www.treasury.gov/initiatives/financial-stability/about/Pages/default.aspx>

<sup>50</sup> Tangible measure over the physical capital stock in the model features no trend during the last decade. This is not true about other measures of equity, so in terms of the model, it is more convenient to use tangible equity aside from the issues described in the previous section.

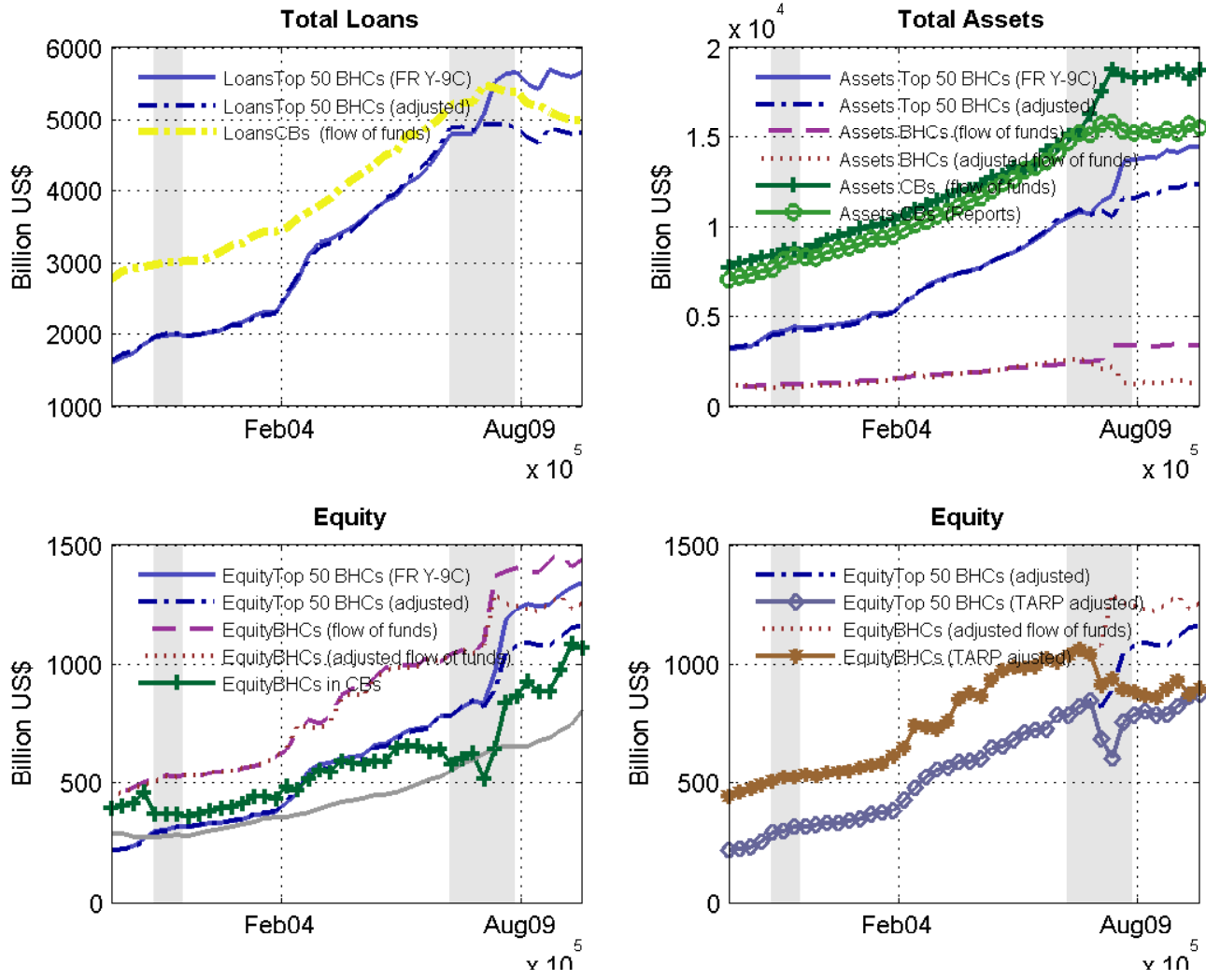


Figure 7: Relationship between adjusted sample and Flow of Funds banking aggregates.

of these expenditures are salaries. To improve the realism of the model, I assume bankers pay a constant amount of their equity every period and a constant bonus when profits are positive. I interpret this cost as financial management costs. This parameter corresponds to  $\psi$  in Table 1.

**Capital Requirements.** Capital requirements can be modeled by introducing a wedge into the LLC. Assuming that the capital requirement is such that banks are not allowed to lose more than a fraction  $\theta$  of equity in a given period, the LLC reads:

$$-\Pi(X, X') Q \leq (1 - \theta) n'.$$

**Physical Capital Cost.** I introduce an additional parameter so that the cost of unit of capital is not one. Since production is linear, this parameter is observationally equivalent with the mean of TFP. I introduce it so that I can use the estimated process for TFP described in the next section.

## 6.4 Parameters

**Calibrated Parameters.** This section describes the calibration of the quantitative exercises provided in the subsequent sections. I set  $\beta$  so that the risk free rate in the deterministic frictionless version of the model

Variable	Model Equivalent	Data Notes
Deposits / Loans	$p(\omega) \omega K$	C&I + real estate + leases + consumer loans
Loans + Interest Income	$q(X) \mathbb{E}_\phi [\lambda(\omega)   \omega < \omega^*(X)] \omega K$	Loans+ net interest income
Net Interest	$q(X) \mathbb{E}_\phi [\lambda(\omega)   \omega < \omega^*(X)] - p(\omega)$	Net interest income / loans
Equity	N	Tangible net-worth
Size of Financial Sector	$\kappa$	Tangible net-wor/ capital stock
Fixed costs	$\psi$	Average non interest net-expenses / N
Leverage	$\frac{p(\omega)\omega}{\kappa}$	Loans / $\kappa$
Bank ROE	$\frac{[q(X)\mathbb{E}_\phi[\lambda(\omega) \omega<\omega^*(X)]-p(\omega)]}{\kappa} - \psi$	
Bank ROA	$\frac{[q(X)\mathbb{E}_\phi[\lambda(\omega) \omega<\omega^*(X)]-p(\omega)]-\psi\kappa^{-1}}{p(\omega)}$	
Dividends	d	$(\Delta N \text{ -profits})^-$
Equity Injections	e	$(\Delta N \text{ -profits})^+$

Table 1: **Data and Model equivalences.**

is 3.0% in annual terms. The discount factor for the financial sector's discount factor  $\beta^f$  is the same. The return to equity in stage two,  $R^b$ , is set to 1, if banks could hold reserves that earn no interest. I assume that the aggregate depreciation rate of the economy is a constant  $\bar{\lambda}$  equal to 0.9756. This leads to an annualized depreciation rate of 10%, which is commonly found in the literature. In this economy, this parameter gives a lower bound to the growth rate of the economy. The fraction of capital good producers  $\pi$  is set to 0.1. This number is consistent plant investment frequencies found in [Cooper et al. \(1999\)](#). This is a standard calibration for models where investment activities are segmented (see [del Negro et al. \(2010\)](#), for example). I set the banker's exit rate,  $\rho$ , to 0 so that they face infinite horizon problems.  $\tau$  is calibrated to be consistent with a marginal cost of equity of 10% and tax-rate on dividends 30%. These values follow from the estimates of the dynamic corporate finance model of [Hennessy and Whited \(2005\)](#). I set the wedge in the LLC  $\theta$  to 8% so that it is made consistent with Basel-II requirements.

**Estimated Parameters.** I estimate an  $AR(1)$  process for  $\log(A_t)$ . I obtain a series for TFP dividing U.S. output by the capital stock reported by NIPA (details are presented in the data appendix). The autocorrelation coefficient is estimated to be 0.993. Its mean is  $-0.885$ , and the standard deviation 0.0083. I assume that  $\phi$  follows a four-state Markov chain. The transition matrix for this Markov chain is estimated using a property of the model. In the model expected profits are positive, but worst-case profits must be negative in equilibrium. For example, if  $\phi$  takes only two values, positive profits are associated with the lowest value of  $\phi$  and negative profits with its largest value. I use the series for bank profits to estimate the transition probabilities for  $\phi$  in that case. This transition probability is crucial to determine expected profits and therefore, the value of equity injections. In the calibration I use a four state Markov chain in order to compare the responses to large and small shocks to  $\phi$  that affect bank equity by different magnitudes.

**Matched Parameters** Calibrating the quality distributions associated with each  $\phi$  represent the biggest challenge. To do so, I use the same parametric form as in the examples introduced in Section 5:

$$\mathbb{E}[\lambda(\omega, \phi) | \omega \leq \omega^*] = \lambda_L + (\bar{\lambda} - \lambda_L) F_\phi(\omega^*).$$

As explained in that section, this parametric form is consistent with Assumption 1.  $\lambda_L$  is the lowest depreciation and  $F_\phi(\omega^*)$  is any CDF with support in  $[0, 1]$ . I set  $\lambda_L = 0$  to have the interpretation that some capital units are worthless. As in the examples in earlier sections, I use the Beta-CDF for  $F_\phi$ . The Beta

Parameters	Value	Note
Calibrated		
$\beta$	0.987259	3% annual time discount rate
$\beta^f$	0.945742	3% annual time discount rate
$R^b$	1	0 interest on reserves
$\pi$	0.097342	Cooper et al. (1999)
$\tau$	0.08	Hennessy and Whited (2005)
$\psi$	0.08	Bank non-interest expense per net-worth
$\theta$	0.08	Basel-II capital requirements
Estimated		
$\mu_A$	-0.885	Estimated TFP process
$\rho_A$	0.993	Estimated TFP process
$\sigma_A$	0.0083	Estimated TFP process
Matched		
$A_L$	3.9	To match bank ROA and leverage
$A_h$	4	To match bank ROA and leverage
$B_L$	6.2	To match bank ROA and leverage
$B_H$	5.2	To match bank ROA and leverage
$\Phi$	[0.95 0.95; 0.05 0.05] $\otimes$ [0.95 0.95; 0.05 0.05]	To match profit transition of banks

Table 2: **Parameter Values**

distribution is convenient because it has two parameters: it is very flexible and bounded between 0 and 1. In the applications, for each  $\phi$ , there are parameters denoted by  $(A_\phi, B_\phi)$  that summarize the quality distribution associated with that state.  $A_\phi$  and  $B_\phi$  are uniformly spaced between  $[A_L, A_H]$  and  $[B_L, B_H]$  respectively. Thus, there is a total of four parameters that characterize a total of four quality distributions.

To set these parameters, I use another property of the model. These are set so that they match four moments: historical and Great Recession levels for bank leverage and bank ROA. Other banking indicators like financial GDP mean  $\kappa$ , and financing premia will follow from these parameters. Notice that bank ROE is tied down by the values of  $\beta^f$  and  $\tau$ , which determine the injection and payout decisions of bankers.

In the model, the difference between the expected value of capital and the cost of capital are the bank's ROA. The cost of capital is given by the supply schedule obtained by solving the k-producer's portfolio problem. This supply schedule is only a function of  $[A_L, A_H, B_L, B_H]$  and the transition matrix of  $\phi$ . The demand for capital is also a function of these parameters and the real-side parameters. Hence, bank ROA will be pinned down by these parameters. In addition, the bank's leverage is the inverse of worst case losses, also function of  $[A_L, A_H, B_L, B_H]$ . Using this property, I try to obtain numbers that resemble leverage and ROA from the U.S. There are four parameters for four moments (two unconditional moments, and two moments for crisis episodes). However, since these parameters affect the outcome of other moments, I am forced to make some compromises to obtain reasonable numbers as discussed in the following section, so the approximation is far from exact.

In addition, I set the non-interest expense parameter  $\psi$  to 8%. This matches the non-interest expenditures to equity ratios for the selected sample of BHCs. Table 2 summarizes the parameter values used in the following quantitative exercises.



## 6.5 Results

Since I am forced to make compromises along different dimensions of the model, the results in this and the following sections should be taken as illustrative examples. Nevertheless, I believe the lessons remain valid.

### 6.5.1 Invariant Distribution and Historical Histograms

Figure 8 reports four histograms. These correspond to the invariant distributions of  $\kappa$  and the growth rate of  $K$ , both in the model and the U.S. data. The heights of the bars represent occupation frequencies.

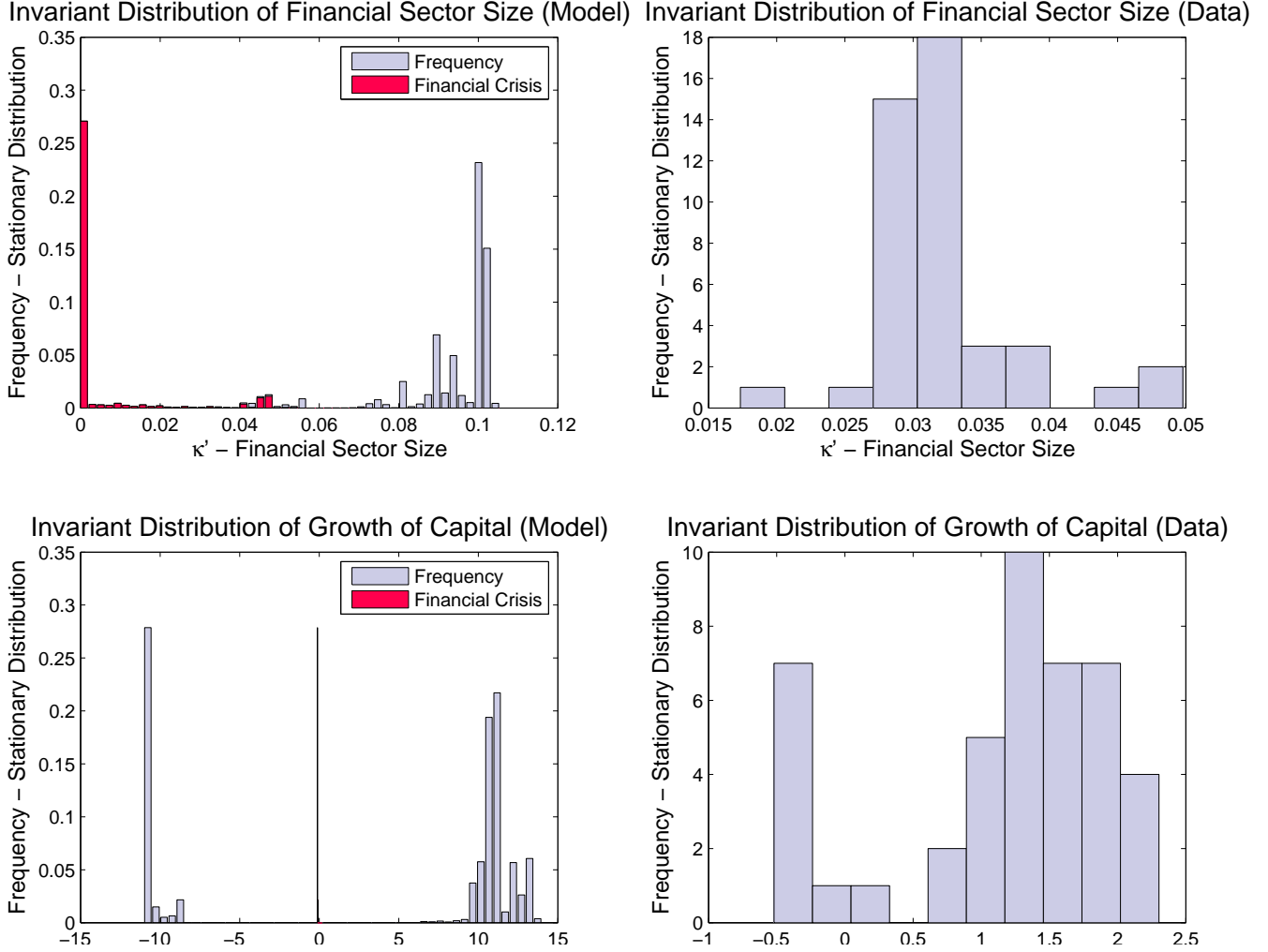


Figure 8: **Invariant distribution and empirical distributions.** The figure reports the invariant distribution of  $\kappa$  obtained from the model and its empirical counterpart. The analog for the growth rate of the capital stock is also included.

The top-left panel depicts the marginal invariant distribution of  $\kappa$ . The top-right panel is the analog for the U.S. data. In the model, the financial risk capacity spends most of time at the right of the distribution. However, there is some probability mass concentrated at the left end of the distribution. A similar concentration mass is also found in the empirical distribution for  $\kappa$  in the U.S. Both histograms also show an empty region between the regions of concentrated probability. In the model, the occupations at the lower end of the distribution occur when a sufficiently bad combination of shocks leads the economy to a financial crises. The

red (darker) bars correspond to the distribution of occupation times within financial crisis regimes. Crises have high occupation times as a consequence of the long exit times from the financial crisis regions. The intermediate intervals, for which  $\kappa$  has no occurrence in the model, correspond to equity injection regions.

The two panels at the bottom of the figure show the behavior of the growth rate  $K$ . The data and the model's distribution of growth rates are very similar. In the model, the concentration region in the lower end is associated with the financial crisis regimes. Figure 1 in the introduction presents a time series version of this correlation that was very sharp during the Great Recession.

### 6.5.2 Model and Historical Moments

Table 3 reports the moments delivered by the model and those from the reconstructed empirical series. These moments are computed from the invariant distribution of the model and from the conditional distribution of crisis states. This section describes these moments and how they relate to other studies on financial crises. The directions of change in the model's moments from normal times to crisis times follow the same pattern as the movements from historical averages to Great Recession statistics. However, the model represents an exaggerated version of reality.

The occupation time on financial crises regimes is 32.6% for the entire sample. The Great Recession represents 14.6% of the time in the sample which is clearly an overstatement since the financial system was very stable prior to this episode. However, [Reinhart and Rogoff \(2009\)](#) calculate that during the national banking era banking crises occurred during 13% of the years in their sample (according to their definition of a financial crisis). The average time the economy takes to leave a financial crisis region in the model is almost 10 quarters. The great recession lasted 6 quarters, twice the length of the average recession.

The average growth rate of the economy in the model is close to the historical growth rate of the U.S. economy. During a financial crisis, output falls to  $-10.0\%$ , a more dramatic figure than the drop in output during the Great Recession. [Cerra and Saxena \(2008\)](#) report a reduction in the growth rate of about 8% for a cross-country sample.

Financial crisis episodes are associated with a strong reductions in volumes of financial intermediation. One can notice this from the reduction in the loans to output ratio in the model. Volumes of intermediation (and quality) also fall in these episodes. This explains also the striking reduction in the investment to GDP ratio. In the model, this ratio is high in comparison with the data. There are no further margins of improvement here unless the discount factor is lowered. This ratio is affected by the process for  $A$ , and the calibration of  $\pi$  and  $\beta$ .

In addition, the model also delivers predictions about the contribution of the financial sector's added value to GDP. In the model this figure is close to 12% in normal times. This contribution falls to 1.6% during the crisis regime because the profits of the sector are very low. Financial GDP during the Great Recession slightly increased.

The second block of moments reports indicators for measures of financial intermediation. The most important of these is the value of  $\kappa$ . This figure is larger than in the data's historical averages but falls to a smaller number when comparing a financial crises regime with the Great Recession. During a financial crises,  $\kappa$  can fall up to 92% in a given period given the nature of the LLC. This is a more dramatic swing than during the Great Recession where  $\kappa$  decreased by 30%. Clearly, the dynamics of the model are more extreme than those in the data.

The unconditional financing premia in the model are also magnified. Financing premia during the crises

falls in the data but increase in the model. However, the behavior of corporate bond spreads did show substantial increases during the crises, as reported by [Gorton and Metrick \(2010\)](#).

For this calibration, bank ROE is higher within crisis episodes. The direction of the drop may depend on the parameter choice. During the period of impact, an adverse shock to  $\phi$  will impact negatively on bank ROE. However, in equilibrium, bank ROE will belong to an interval determined by the inaction regions. Nothing precludes the distribution bank ROE within financial crisis regimes to be smaller than their unconditional average. Bank ROE, in fact, will increase slowly as the financial sector builds net worth to the point where injections occur at higher than average levels.

Growth in the model is entirely explained by capital accumulation. During a financial crisis,  $TFP$  is responsible for some portion of growth. Why?  $TFP$  is mean reverting, and financial crises are most likely to occur in periods of low  $TFP$  because this reduces bank profits and the incentives to recapitalize banks. Hence,  $TFP$  is expected to recover during crisis episodes. A variance decomposition of the model shows that during normal times, most of the volatility of output growth is due to movements in lending conditions that affect the accumulation of capital. During a financial crisis, financial intermediation is responsible for a smaller share of volatility because crises occur more often in low  $TFP$  states.  $TFP$  is mean reverting, explaining a higher  $TFP$  component of volatility.

Variable	Unconditional	Crisis	Historical	Great Recession
Occupation Times				
Occupation Time	100%	32.6%	100%	14.5%
Duration (quarters)	-	10.26	20.8	6
Economic Activity				
Average Growth Rate	4.3%	-10.3%	2.98%	-2.36%
Investment/Output	39.9%	-0.935%	8.51%	5.64%
Investment/Capital	3.58%	-0.0644%	6.09%	3.92%
Financial GDP/GDP	12.3%	1.59%	4.4%	5.44%
Financial Intermediation Indicators				
Average $\kappa$	0.0659	0.0048	0.0162	0.0148
Financial Leverage	6.56	1.99	9.87	11.3
Loans Output	6.68%	0.0832%	NaN	NaN
Return to Assets (ROA)	6.94%	16.9%	1.18%	-0.0839%
Return to Equity (ROE)	31.3%	48.1%	16.4%	-1.07%
Financing Premia	39.5%	106%	6.25%	5.89%
Financial Equity Indicators				
Average Dividend Rate	0.643%	0.0193%	1.12%	-18.8%
Financial Stocks Index	100%	8.31%	100%	42.9%

Table 3: Model moments and reference statistics.

### 6.5.3 Response to Dispersion Shocks

Figure 13 shows the response of the economy to an increase in  $\phi$ . The figures plot the expected responses of equilibrium objects after  $\phi$  takes its largest value. The system is initiated from states randomly drawn from the invariant distribution. The top-left panel shows the immediate effect on bank losses. The solid line in the panel corresponds to the banking system's liabilities relative to their unconditional mean. The dashed line presents the corresponding series for bank assets. When the shock is realized, the value of assets falls under the value of liabilities because  $\phi$  affects the value of the capital bought by banks. This discrepancy induces a

reduction in bank profits (dashed line in top-middle panel) during the period of impact. Whereas expected profits (solid line in top-middle panel) are constant, profits fall below their expected value. The reduction in profits causes a reduction in the financial risk capacity in the period after the shock (top-right panel). As a consequence, during the subsequent periods, the equilibrium  $\omega^*$  (middle-left panel) falls in response to the lower financial risk capacity. The fall in  $\omega^*$  represents both a decrease in financial intermediation and an exacerbation of adverse selection. After the period of impact, one can observe that banking activities decline as both assets and liabilities fall.

In reaction to this shock, on average, banks inject equity. However, these injections are small in relation to the drop in  $n$  and are far from replenishing bank equity immediately. The value of bank net worth also declines, almost entirely driven by the reduction in  $\kappa$  (middle-right panel).

The effects on real economic activity are depicted in the bottom row. The reduction in financial intermediation in the periods after the shock cause a drop in investment (bottom-left panel). Since this economy requires investment to grow, unsurprisingly, the growth rate of the economy declines (bottom-middle panel). The panel in the bottom right shows the level of output with and without the shock. Because this is a linear-production growth model, the reduction in growth rates have permanent effects.

The effects of  $\phi$  have the hallmarks of the descriptions of financial crises where adverse selection is aggravated and where financial intermediation declines severely as in, for example, [Calomiris and Gorton \(1991\)](#) or [Mishkin \(2011\)](#).

One thing to note is that the reduction in the growth rate is very persistent despite the fact that the shock has virtually no memory. This persistence is a result of the internal behavior of the system. Several macroeconometric studies obtain highly persistent filtered time series in financial shocks that affect firm decisions (e.g., [Christiano et al. \(2009\)](#), [Justiniano et al. \(2010\)](#) or [Jermann and Quadrini \(2011\)](#)). Through the lens of the model, these long recoveries can be explained by the time banks take to rebuild net worth. However, this persistence only occurs in response to large shocks but not to small shocks.

**Inherent Non-linearities.** Let us consider now the response to a smaller shock  $\phi$ . Figure, [14](#) presents a superimposed impulse response to the system to a shock to this smaller size on the impulse response in Figure [13](#). It is clear that the responses to smaller shocks are much less persistent. In particular, the growth rate of the economy recovers almost immediately after the small shock. Naturally, bank losses are smaller for the smaller shock, and except for expected bank profits in the period after the shock, the directions of the responses are virtually the same for all the variables. So what explains this sharp differences in persistence? In contrast to what happens after large shocks, adverse-selection effects are not strong when small shocks occur. Hence, after small shocks, competition effects lead to higher marginal profits with less intermediation. This explains the differences in the directions of expected profits. With higher expected profits, equity injections are attracted. Notice that these are massive, almost twice the size of the average dividend payment. These equity injections mitigate the amplification of the shock. Higher profits imply that by retaining earnings,  $\kappa$  will increase rapidly in the subsequent period after the small shock is realized, something that fails to occur after large shocks. This feature explains the inherent non linearity that this paper attempts to underscore.

## 7 Financial Stability Policies

This section discusses some potential policies aimed at restoring financial stability. I begin describing the possible externalities that may arise in this environment and then discuss the effects of several policies.<sup>51</sup>

### 7.1 The Externalities

There are two externalities in this environment. The first stems from excessive intermediation in competitive inaction regions. The second externality is the coordination failure that occurs in financial crises regimes.

**Intermediation Externality.** [Hanson et al. \(2011\)](#) argue that macroprudential policy frameworks must identify why banks may provide excessive intermediation. Here, when banks purchase large amounts of capital from producers (when they are highly levered), they face greater potential losses in net worth. Banks lever up rationally: they take into consideration risks and benefits. However, because they are price takers, they fail to internalize this if they lose financial risk capacity together. They induce market responses on prices and on the capital qualities traded. Although this is also the case in a neoclassical growth model, the fact that net worth is an endogenous state variable alters things. A planner facing the same constraints as banks would take into account the impact on the aggregate net worth. In particular, in a competitive inaction region, a planner may choose to provide less intermediation to reduce extreme outcomes after bank losses. In turn, banks are better off as less intermediation in competitive inaction regions leads to greater profits. Producers may also be better off because the economy can be more stable with less intermediation, and they are risk averse. Thus, in these regimes, excessive financial intermediation induces a negative externality.<sup>52</sup>

**Equity-Injections Externality.** In financial crisis regions, there is a coordination failure: when  $\kappa$  is low, bankers expect low future discounted profits. Given this projection, an individual banker will not inject equity because he cannot affect  $\kappa$ . However, if all bankers were to inject capital simultaneously, by definition, the value of bank equity would increase. This makes bankers better off and more intermediation makes producers better off also. The following sections discuss the effects of alternative government policies on this environment.

### 7.2 Capital requirements

**Effects of Capital Requirements.** Increasing the capital-requirement parameter  $\theta$  has two effects. The first is direct. Given a level of  $\kappa$ , this increase will lower the volume of intermediation in a given period. As discussed in the previous section, this policy may be desirable if banks are intermediating excessively. Though, in general, a reduction in their intermediation will have adverse effects on growth. The effect on the volume of intermediation is clear from the LLC:  $\Pi(X, X')Q \leq (1 - \theta)n', \forall X'$ . This constraint is tighter as  $\theta$  is increased. Depending on the region, the reduction in  $Q^*$  may decrease or increase bank profits (depending on whether competition or adverse selection effects dominate), and the same is true about leverage.

The second effect is the indirect dynamic effect on  $\kappa$  caused by the reduction in the profitability of intermediation. Holding prices fixed, an increase in  $\theta$  reduces bank ROE. This happens because it forces bank leverage down: from the solution to  $Q^*$ , one can show that the shadow value of relaxing the bank's LLC is  $(1 - \theta) \max \left\{ \frac{\mathbb{E}[v_2^f(X')\Pi(X, X')]}{-\min_{\bar{X}} \Pi(X, \bar{X})}, 0 \right\}$ . This expression is a linear negative function of  $\theta$  if  $\Pi(X, X')$  is fixed. This

<sup>51</sup>[Hanson et al. \(2011\)](#) refer to similar externalities, but in their line of thought, these are caused by a combination of debt overhang problems and fire sales externalities. Nonetheless, they discuss the effects of the same policies that I refer to here.

<sup>52</sup>[Lorenzoni \(2008\)](#) discovers a similar externality in the context of fire-sales.

effects shows up in the conditions that determine the marginal value of bank's equity:

$$\tilde{v}(X) = \beta^F \left[ \mathbb{E}[v_2^f(X')] + (1 - \theta) \max \left\{ \frac{\mathbb{E}[v_2^f(X')\Pi(X, X')]}{-\min_{\tilde{X}} \Pi(X, \tilde{X})}, 0 \right\} \right]$$

Holding profits fixed, the value of bank equity is decreasing in  $\theta$ .

These two effects operate in different directions in determining the equilibrium intervals for  $\kappa$ . Reductions in volumes may increase or decrease the value of bank equity. The reduction in bank leverage reduces bank ROE (by lowering leverage) and this reduces the incentive to inject equity.

As argued earlier, a social planner will face a trade off between reducing probability of a financial crises at the expense of a reduction in financial intermediation. Capital requirements may be a useful tool in inducing more favorable outcomes. An optimal government policy potentially involves a state dependent  $\theta$ . However, the effects on  $\kappa$  will be hard to pin down without specific values of parameters. The following numerical exercises attempt to shed light on how these effects balance out in the current calibration.

**Invariant Distribution and Moments under Basel-II and III.** This section describes the effects of an increase in  $\theta$  from 0.08 to 0.18.<sup>53</sup> These numbers are chosen to match the regulatory constraints imposed by the Basel-II to Basel-III frameworks. Figure 9 presents the invariant distribution of  $\kappa$  under both parameter values. Both distributions are similar in that they show a bimodal shape with concentrated probability masses at the extremes. However, there are important differences. First, the distribution under Basel-III has less concentration for lower values of  $\kappa$ . This means that the unconditional probability of falling in financial crises regimes is lower. Second, towards the right end of the support of these distributions, the probability mass under Basel-III is higher. Higher average levels of  $\kappa$  can result from higher profitability from intermediation that compensate a lower degree of intermediation.

Table 4 reports moments under both policy regimes. The duration of a crisis is shorter under Basel-III. Why? Crises last less during Basel-III because this regime prevents large falls in  $\kappa$ . Since the financial risk capacity is higher on average,  $\kappa$  can reach an equity injection region in less time. In addition, because declines in  $\kappa$  are less extreme, financial crises are also less frequent. It takes less likely combinations of  $\phi_t$  to cause a financial crisis. This figure is also consistent with higher levels of  $\kappa$  observed both unconditionally and for crisis regimes. With higher levels of  $\kappa$  the economy grows at faster rates.

Variable	Basel-II		Basel-III	
	Unconditional	Crisis	Unconditional	Crisis
Occupation Time	100%	32.6%	100%	19.77%
Duration (quarters)	-	10.26	-	3.89
Average Growth Rate	4.3%	-10.3%	9.3%	-9.61%
Average $\kappa$	0.0659	0.0048	0.100	0.01

Table 4: **Comparison of Moments Under Basel-II and III in the Model.** The table plots some moments corresponding to values of  $\theta$  equal to 0.08 (Basel-II) and 0.18 (Basel-III).

**The Timing of Basel-III.** This section studies the effects of increasing capital requirements unexpectedly and permanently once the economy is in a financial crisis. The purpose of this exercise is to study the recovery from a financial crises region under Basel-II and Basel-III values of  $\theta$  once the economy is on a financial crises

<sup>53</sup>A similar exercise is performed by Bianchi (2011) in the context of international capital flows.

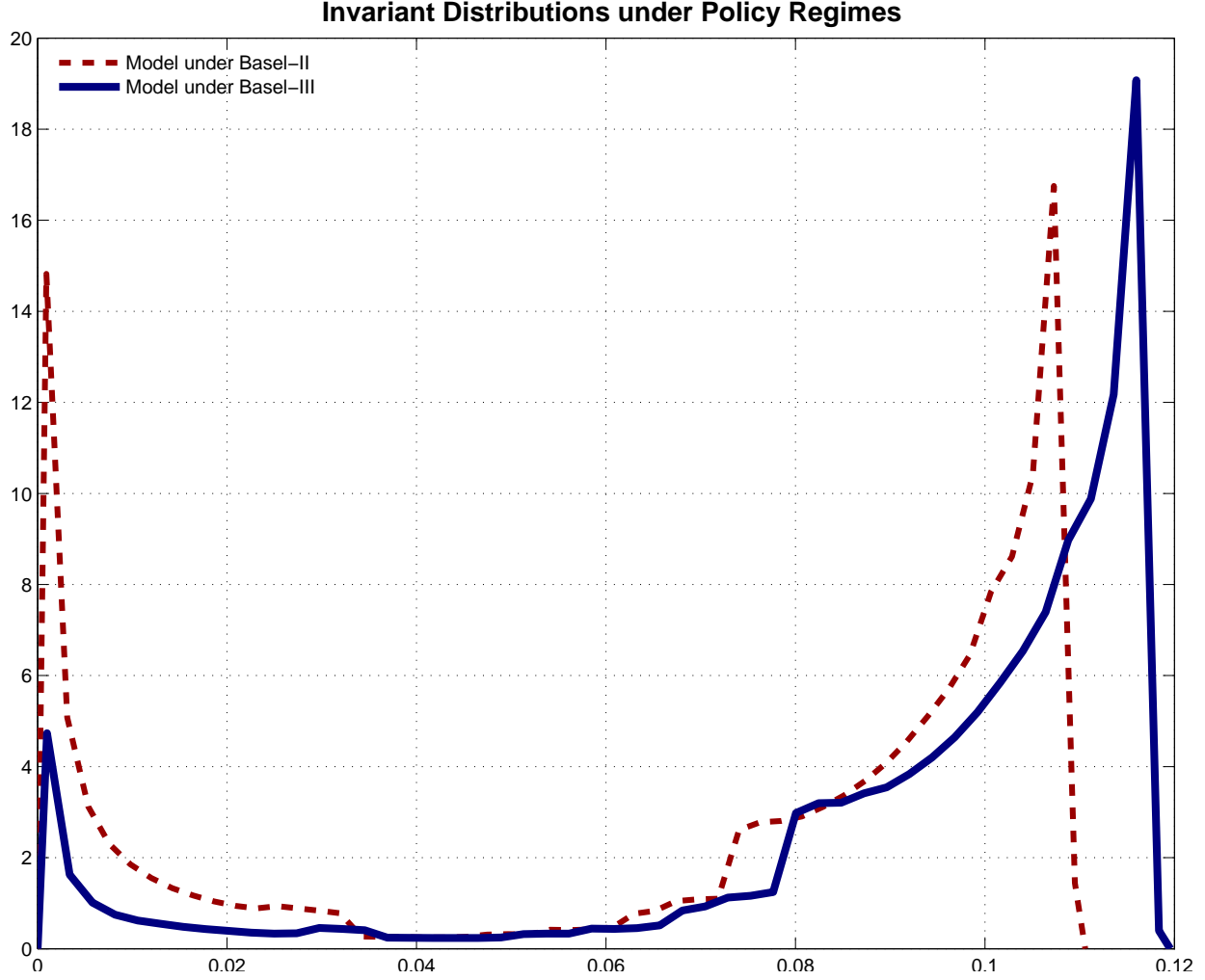


Figure 9: **Invariant Distributions Under Basel-II and III and Historical Histogram.** The figure plots the invariant distribution of the financial risk capacity for values of  $\theta$  equal to 0.08 (Basel-II) and 0.18 (Basel-III).

under Basel-II. To do so, I initialize the economy from random states drawn from the Basel-II distribution of financial crisis states. Then, I compare the growth rates if the economy remains under Basel-II or if Basel-III is introduced permanently. Figure 10 presents the paths for these growth rates under both policy regimes.

One can observe that the recovery under Basel-II is faster. The intuition behind this outcome is that once in a crisis, capital requirements may prolong the decline. Higher capital requirements will depress intermediation while exacerbate adverse selection and this will reduce the profitability from banking even more. As a consequence, this will postpone the recapitalization of banks. There is no inconsistency with the results in the previous section that show that crises last less under Basel-III. This is because the economy starts at even lower levels of  $\kappa$  under Basel-II.

Comparing this with the previous exercise, the model warns policy makers what not to do in bad times or what they should have done during good times. There is currently an ongoing debate between bank managers and policy makers (see [Admati et al., 2011](#)). Bank managers argue that increasing capital requirements immediately after a crises may be to stringent on financial intermediation. In the model, higher capital requirements during a financial crisis will carry two effects: (1) they will aggravate adverse selection and (2)



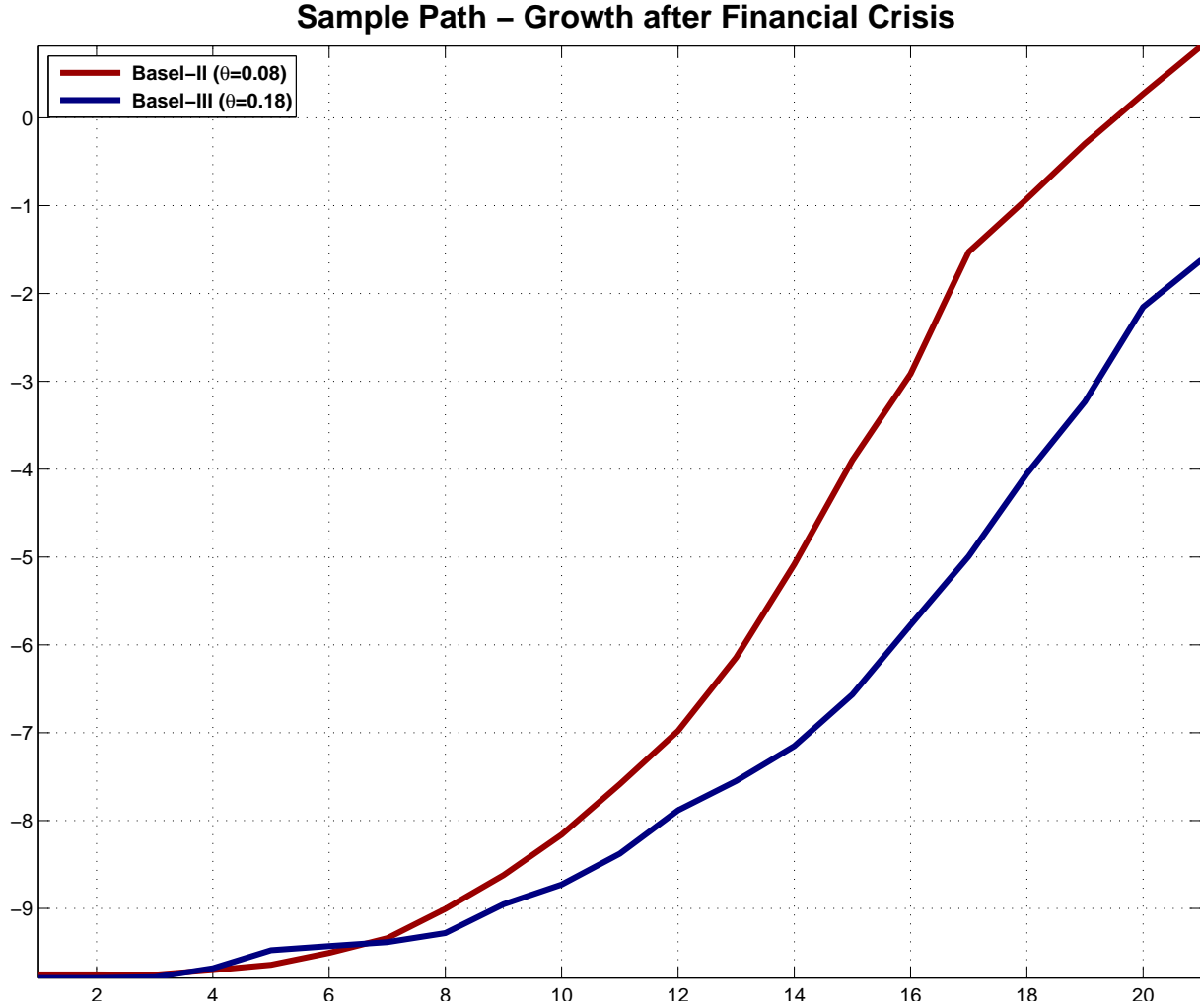


Figure 10: **Expected Growth Recovery Path Under Basel-II and -III.** The figure plots the expected path of the growth rate of the economy for  $\theta$  equal to 0.08 (Basel-II) and 0.12 (Basel-III). The economy is initiated from random draws of the conditional distribution of crisis regimes under Basel-II parameters.

they will reduce the incentives to recapitalize banks and thereby prolonging the crisis. The first effect is also shared by other models with fire-sale externalities (see, for example, [Bianchi \(2011\)](#) or [Hanson et al. \(2011\)](#)). However, if marginal profits from intermediation are decreasing, the additional constraints on intermediation will be offset by higher marginal profits (the effect on bank ROE could be indeterminate). If bank ROE increases, this would ultimately shorten the crisis by attracting more equity. In this model, bank ROE as a function of  $\kappa$  must necessarily fall within higher requirements, so the effect is necessarily damaging.

[Admati et al. \(2011\)](#) argue, furthermore, that capital requirements will only affect the composition of bank liabilities because banks will fund with more equity with debt. This can be achieved without reducing the banks' activities because investors can be compensated with less risk. This is not a possibility in the model because I do not allow producers to be equity holders of banks. Their assumption is realistic, as long as there is a low elasticity of substitution between debt and equity financing in the banking industry.

**Pro-Cyclical Capital Requirements.** The results in the previous sections suggest that pro-cyclical requirements are perhaps the optimal policy. In competitive inaction regions, higher requirements may prevent large swings in  $\kappa$ . However, during crisis regimes, by increasing bank profitability at times when adverse

selection is severe, lower requirements may shorten the length of a crisis. [Kashyap and Stein \(2004\)](#) argue in favor of pro-cyclical requirements because they view that lending should be promoted during crisis times. In a related model, [Bianchi \(2011\)](#) performs this type of exercise.

### 7.3 Dividend Taxes

**Effects of Dividend Taxes.** [Admati et al. \(2011\)](#) proposed restricting bank dividends in the aftermath of the great recession. This is similar to increasing tax dividends in the model. From a static perspective, increasing dividend taxes reduces the benefits of dividend payoffs so it has a direct effect on increasing bank equity. The timing will matter: Bankers will cut-back on dividends as long as they believe the increase is temporal. If they expect a relative increase in dividend taxes in the future, the value of bank equity will fall. Thus, the second effect of dividend taxes is to affect the value of equity, ex ante, which may lead to the opposite effect as desired.

These effects can be analyzed by considering the bank's dividend policy. Assume that the dividend tax is increased by  $\Delta$ , for a given period. Then, as shown earlier,

$$d > 0 \text{ only if } \beta^F \left[ \mathbb{E}[v_2^f(X')] + \max \left\{ \frac{\mathbb{E}[v_2^f(X') \Pi(X, X')]}{-\min_{\tilde{X}} \Pi(X, \tilde{X})}, 0 \right\} \right] \leq (1 - \tau(1 + \Delta)).$$

It is clear from this expression that, once and for all, increases in dividend taxes reduce the incentives to payout dividends. Nevertheless, if tax increases are anticipated by markets, this would then show up in the marginal value of equity:

$$\tilde{v}(X) = \beta^F \mathbb{E} [\min \{ \max \{ \mathbb{E} [\tilde{v}(X'') | X'] , 1 - \tau(1 + \Delta) \} , 1 \} | X] .$$

This expression shows that  $\tilde{v}(X)$  would be lower with a permanent increase in taxes. Perceived dividend taxes thus have the effect of reducing the equilibrium financial risk capacity, but it is not clear how this will affect the dynamics.

### 7.4 Government Sponsored Equity Injections

**Effects of Equity Injections.** In times of crises, equity injections allow the government to recapitalize the financial system. This policy may prevent the negative consequences of adverse selection. In the model, privately financed equity injections cease to occur in equilibrium when expected returns to intermediation are low. In crisis regions, this follows from a coordination failure by which bankers fail to inject equity simultaneously to restore the financial risk capacity. Government sponsored equity injections can increase  $\kappa$  and serve as a coordination device.

The drawback of this policy is not captured by the model because the LLC is not modeled from more fundamental forces. This point is formalized in [Philippon and Schnabl \(2011\)](#) and [Philippon \(2010\)](#). In principle, expected government injections may relax the LLC constraints if some parties are being bailed out. Ex ante, this may induce increases in volumes of intermediation, the opposite to desired policy. This government policy can also increase the marginal value of equity that would, in turn, attract more capital to the banking system. With more capital on the banks' balance sheets, the volume of intermediation may increase beyond a desirable level but will also increase the equity buffer. To this, one should add the fiscal

impact of these policies.

## 7.5 Government Asset Purchases

A final policy instrument is the direct purchase of capital by the government. This can be done in two ways. The first is to purchase capital from banks after  $\phi$  is realized. This would prevent banks from suffering losses but would require the government to take losses in bad states. Implicitly, in the model, this can be captured as a direct transfer to bank balance sheets. In terms of the dynamics, this would be equivalent to equity injections discussed earlier with the difference that, with equity injections, the government can later sell bank equity reducing its losses. Again, this policy may lead to a moral hazard problem not modeled here. A second issue is that there are no fire-sales effects here. With fire sales, governments can smooth the impact of immediate sales by banks, ameliorating the problem. Philippon and Skreta (2011) and Tirole (2011) study optimal government purchases in markets with asymmetric information.

A second possibility is that governments participate in purchasing capital directly. This policy can have the effects of improving market conditions, possibly increasing bank ROE. The benefits of this policy will depend on how effective a government can be.

## 8 Discussion of Extensions

This section discusses two extensions to the basic model with the purpose of enriching the discussion.

### 8.1 Spillovers

Kashyap et al. (2008) describe how risks from securitization of banking activities were spilled over to traditional banking activities. So far, capital is ex ante homogeneous, so financial intermediation is a single activity. The model is unrealistic in this dimension because, in reality, banks have a number of product lines and are engaged in intermediation services in different sectors. Intermediation strategies in distinct sectors are differentiated according to information about profitability and risks involved. In reality, profitability and risks are assessed according to firm specific features or specific features of the collateral used. In fact, multidimensional features can explain why financial institutions are not willing to take certain forms of capital as collateral or why several product lines of the financial system froze during the aftermath of the sub-prime crisis. In principle, there is no reason for volumes of intermediation to fall in the same magnitude upon a shock that affects the financial system's balance sheet.

A version of the model with different sectors may be used to analyze how shocks to the value of collateral in one sector (such as housing, for example) may end up spilling over to manufacturing sectors by affecting the balance-sheet of FIs.

In addition, the strategy for financial institutions may also depend on the type of financial instrument employed. A version of the model that also studies different financial products like investment banking can induce spill-over effects by affecting the financial system's balance sheet. This feature can be easily incorporated into the model by analyzing a portfolio-choice problem for FIs in the interim period. In terms of the model, allowing banks to invest their equity in risky assets is like making  $R^b$  stochastic and thus affecting the evolution of bank to the bank's equity.

## 8.2 Fire-sales

In the model, banks are forced to sell assets once they suffer losses from intermediation. So far, they sell the storage good to raise funds. The price is 1 since the bank's equity is held in the commodity that plays the role of the numeraire. The model can be altered to introduce fire sales. For example, the bank's equity may be held in units of capital. In this case, if financial contracts are specified in unit of consumption, upon a shock, banks may then be forced to sell capital at the same time. When this is the case, banks must sell capital units at a lower price, creating a negative spiral effect as in Brunnermeier and Sannikov (2011). This leads to additional externalities, as explained by Lorenzoni (2008), but the policy implications in such environments are very similar (see Bianchi (2011)).

## 9 Conclusions

This paper provides a theory about risky financial intermediation under asymmetric information. The main message of the paper is that financial markets where asymmetric information is a relevant friction are likely to be more unstable than others. The source of this instability is caused by the non-monotonicity in bank profits as a function of the aggregate net worth of the financial industry. This non-monotonicity implies that banks fail to recapitalize during bad times, something that prolongs the crises.

There are many other theories that explain why banks can fail to raise equity immediately after a crisis. These theories can be segmented into two branches of the literature: those that refer to agency costs in the banking industry and those that argue that loan quality and bank equity returns fall with lower intermediation. Throughout the paper, I argue that these differences have different policy implications. Testing the validity of these theories and streamlining what they mean for optimal financial regulation is an important task left for the future.

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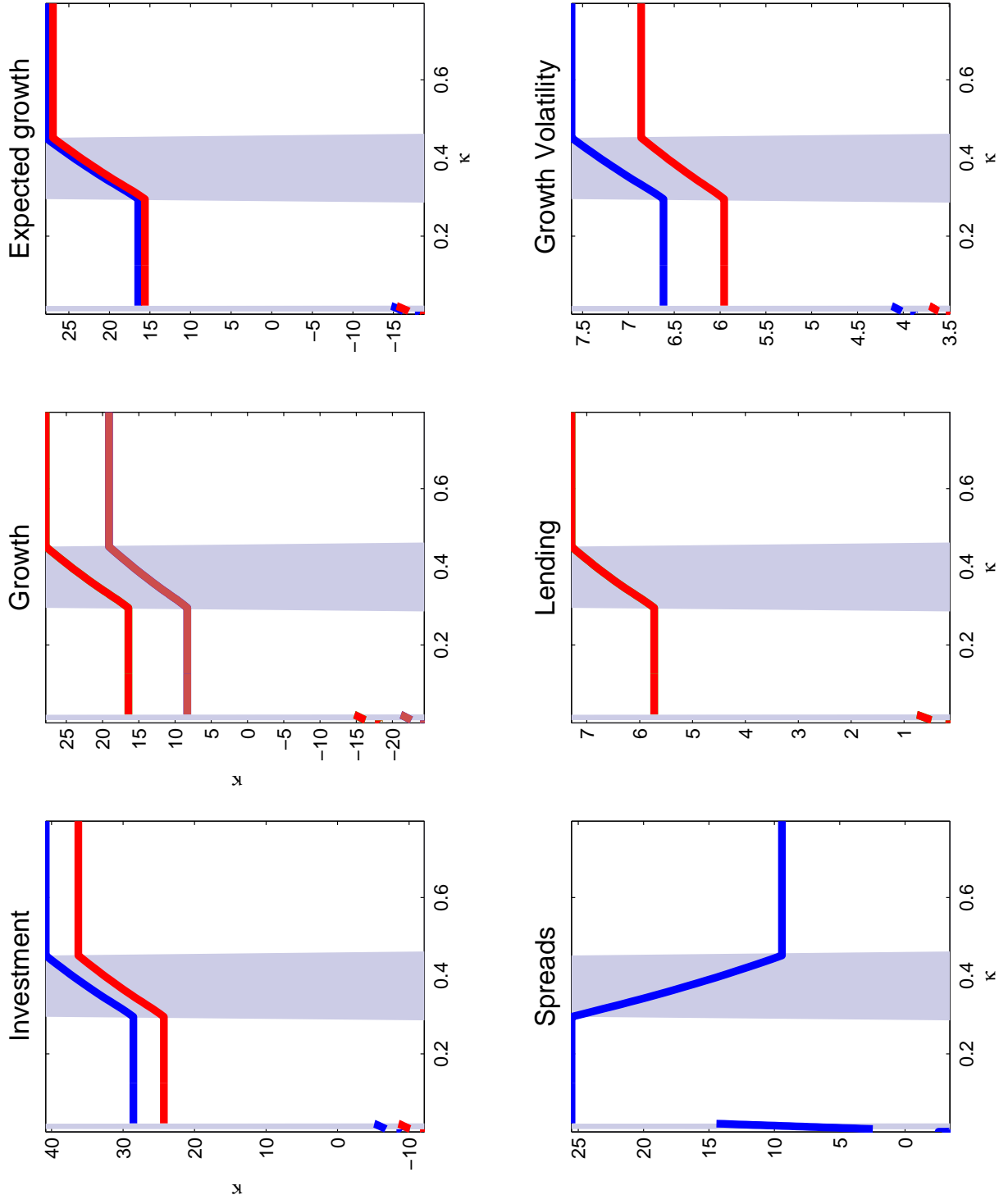


Figure 11: Equilibrium real side in the model with asymmetric information as functions of  $\kappa$ . The figure is constructed by setting parameters to:  $\pi = 0.1$ ,  $\beta = 0.975$ ,  $\beta^f = 0.95$ ,  $\tau = 0.5$  and  $\rho = 1$ .

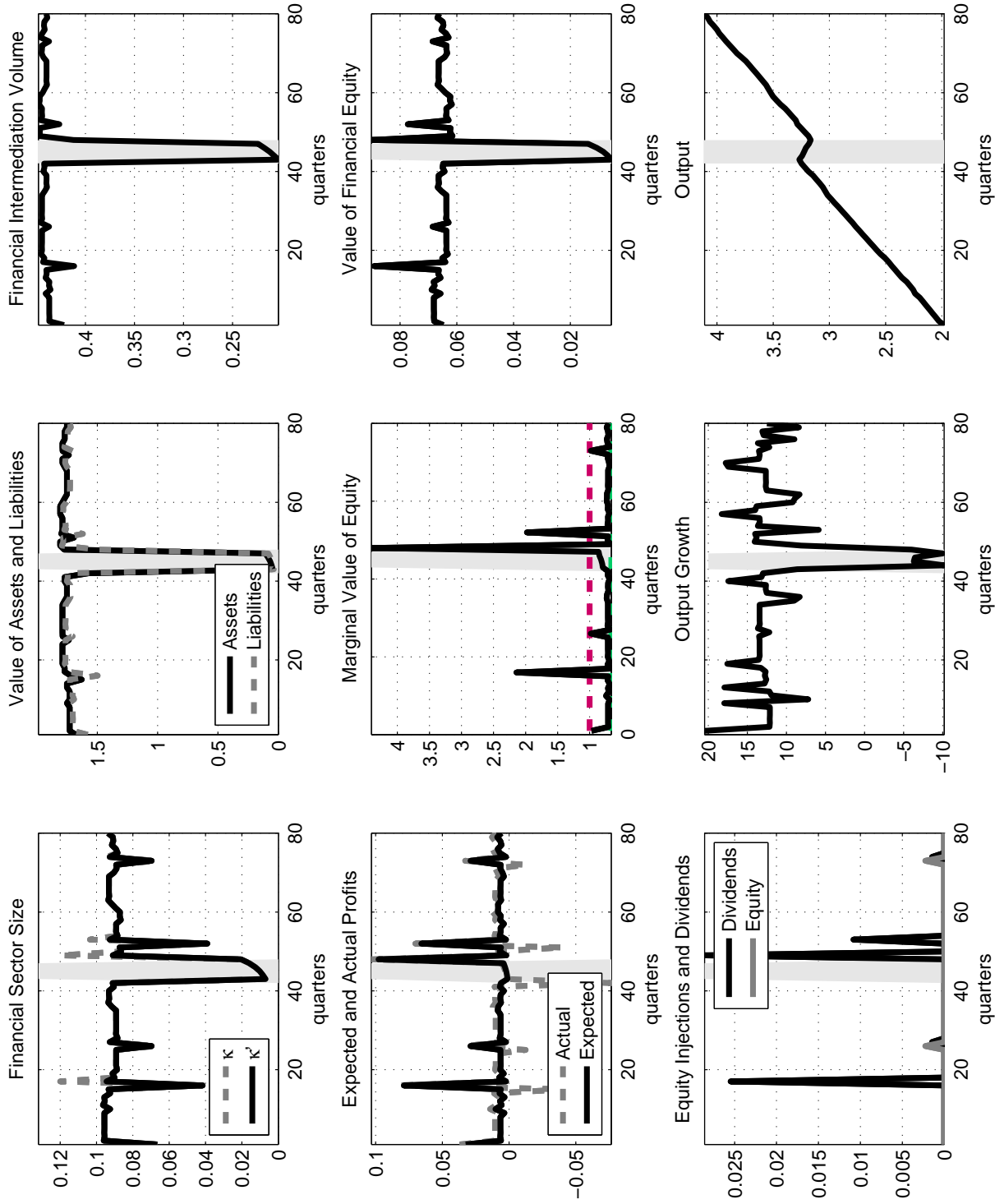


Figure 12: **Simulations.** The figure plots a simulated path for the economy with present asymmetric information. Shaded areas correspond to the financial crisis regimes. The parameters of this simulation are described in the calibration section.

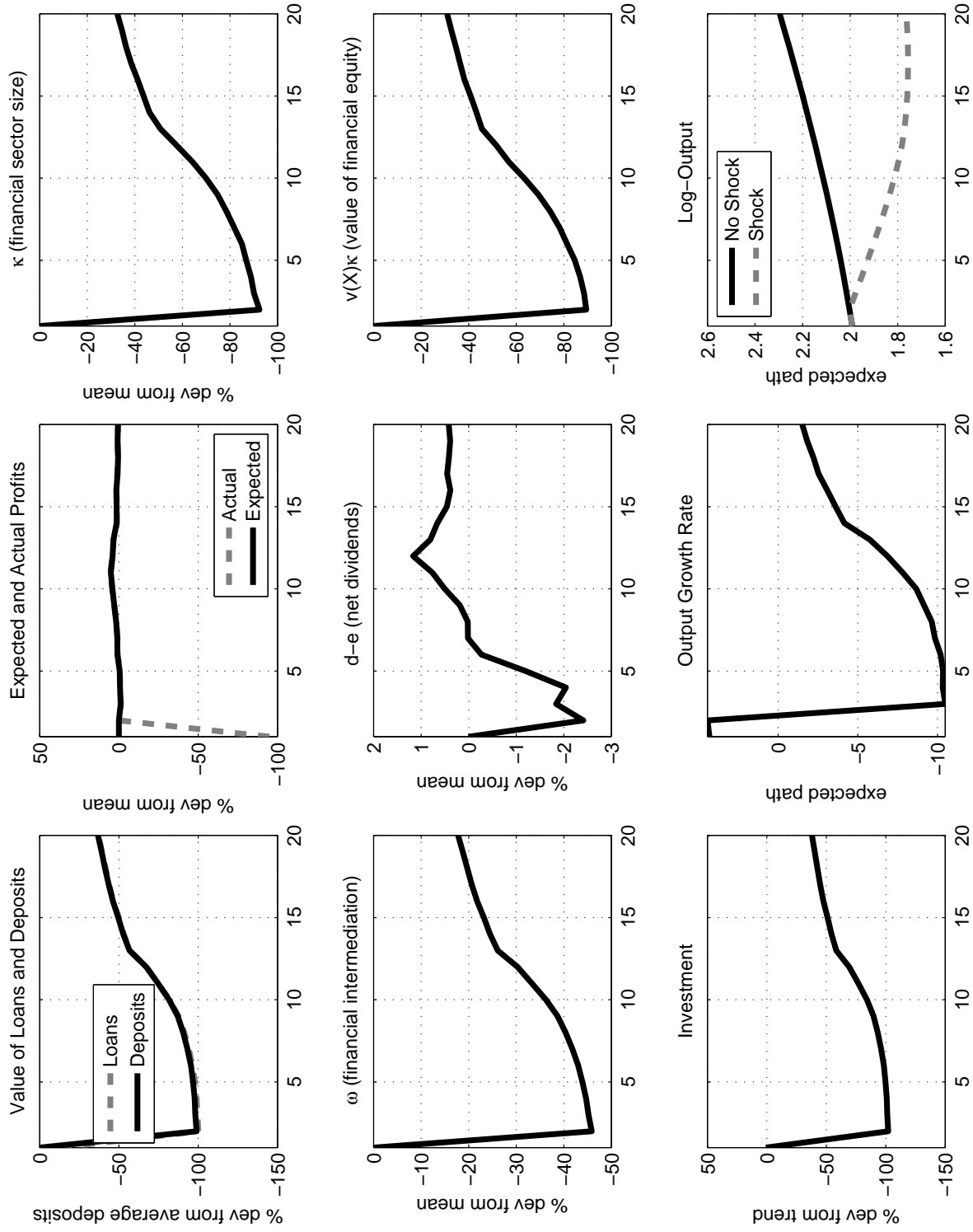


Figure 13: **Impulse response function.** The figure plots the response of the system to a realization of the largest value of  $\phi$ .

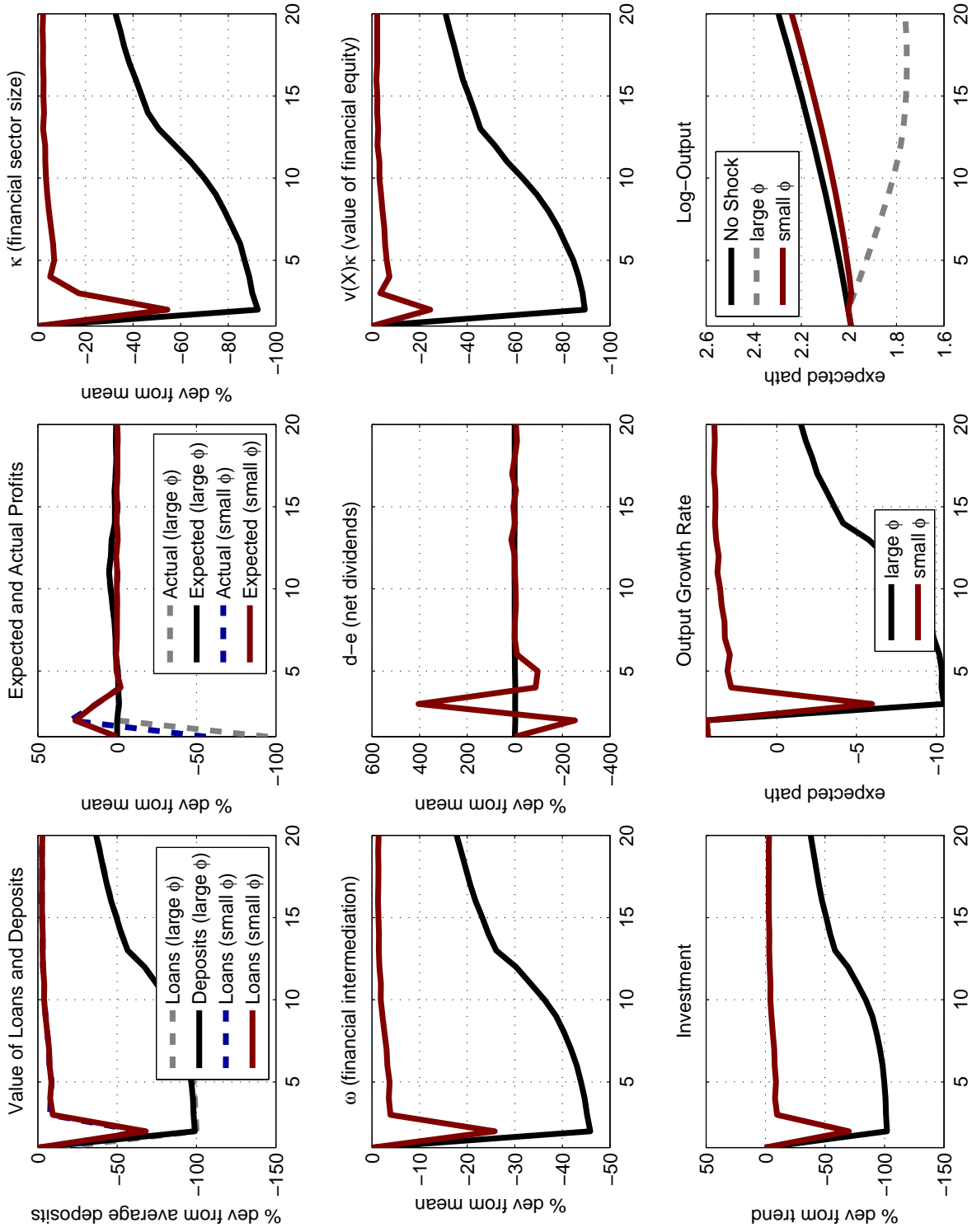


Figure 14: **Impulse response function.** The figure plots the responses of the model to realizations  $\phi$  corresponding that lead to high and small losses for banks.



## A Algorithm

The following algorithm was used to compute equilibria in the model.

**Algorithm 1**    1. *Discretize the state space of  $A \times \phi$  and transition function  $\chi$ .*

- *I use a grid of 20 points for each variable.*

2. *Discretize the unit interval for the volumes of intermediation.*

- *I use a grid size of 1000 points.*

3. *For all possible realizations  $A \times \phi$  and  $\omega$  on the grid solve  $\{\mathbf{p}(\omega, \mathbf{A}, \phi), \mathbf{q}(\omega, \mathbf{p}, \mathbf{A}, \phi), \mathbf{\Pi}(\omega, \mathbf{A}, \phi)\}$ .*

- *$\mathbf{p}(\omega, \mathbf{A}, \phi)$  is discretizing the space of all possible values  $p_L = \min_{\phi} \lambda(0, \phi)$  and  $p_H = \max_{\phi} \lambda(1, \phi)$  and solving the optimal portfolio problem assuming  $\mathbf{q}^c(\omega, \mathbf{A}, \phi) = 1$ .*
- *Using this  $\mathbf{p}$ , one finds  $\mathbf{q}(\omega, \mathbf{p}, \mathbf{A}, \phi)$ ,  $\mathbf{\Pi}(\omega, \mathbf{p}, \mathbf{A}, \phi)$  and checks whether  $\mathbf{q}(\omega, \mathbf{p}, \mathbf{A}, \phi) \geq 1$ .*
- *For values where the condition fails, one solves  $\mathbf{p}(\omega, \mathbf{A}, \phi)$ ,  $\mathbf{q}(\omega, \mathbf{A}, \phi)$  jointly and then finds  $\mathbf{\Pi}(\omega, \mathbf{A}, \phi)$ .*

4. *Guess a candidate function for  $\tilde{v}$ .*

- *I use an initial guess of  $\tilde{v} = (1 - \tau)$ , corresponding to the case when  $\rho = 1$ .*

5. *Compute the set  $\omega^o$  using the candidate function  $\tilde{v}$ .*

- *To do this I interpolate over the upper contour of  $\mathbb{E}[\tilde{v}(X') \mathbf{\Pi}(\omega, \mathbf{p}, \phi) | X]$ .*

6. *Compute the set  $\omega^\kappa$ .*

- *This is done by computing for each  $\omega$  in the grid,  $\kappa = \min_{\phi} \mathbf{\Pi}(\omega, \mathbf{p}, \phi) \omega$ .*

7. *Compute  $\omega^*(X)$  for this iteration. Then, define  $p(X) = \mathbf{p}(\omega^*(X), \mathbf{A}, \phi)$ ,  $\Pi(X) = \mathbf{\Pi}(\omega^*(X), \mathbf{A}, \phi)$  and  $q(X) = \mathbf{q}(\omega^*(X), \mathbf{p}(\omega^*(X), \mathbf{A}, \phi), \mathbf{A}, \phi)$ .*

8. *Compute the transition function for  $X$ .*

9. *Update the  $\tilde{v}(X)$ .*

- *This is done by iterating the Bellman equation for  $\tilde{v}(X)$ .*

10. *Iterate steps 4-9 until convergence.*

- *I used a tolerance of 0.001% for the value of equity  $\tilde{v}(X)$ .*

11. *Compute  $v(X), d(X), e(X)$ .*

*Computation time.* The algorithm runs in 5 minutes in Matlab.

## B Proofs

### B.1 Proof of Propositions 1, 2 and 3

The proof of propositions 1, 2 and 3 is presented jointly. The idea of the proof is to transform the producer's problem into a consumption-savings problem with log-preferences and linear constraints. For this, one has to deal with the asymmetric information problem and the randomization across producer types first. Once this is done, one can use the dynamic programming arguments for homogenous objectives in [Alvarez and Stokey \(1998\)](#) to argue that all the Bellman equations here have unique solutions. I thus, proceed by guess and verify to find these solutions. A similar proofs appear in [Bigio \(2011\)](#).

Define  $W^p \equiv w^p k \equiv (A + q\bar{\lambda}(\phi'))k$  and  $W^i \equiv w^i k \equiv (p\omega^* + q^c \mathbb{E}[\lambda(\omega, \phi') | \omega < \omega^*])k$  as in the main text. The guess for the c-producer's policy function is  $k^{p,i} = \beta \frac{W^p}{q}$  and  $c^p = (1 - \beta)W^p$  and that his value function is of the form  $V_2^p = \psi^p(X) + \frac{1}{(1-\beta)} \log W^p$  where  $\psi^p(X)$  is a function of the aggregate state. For k-producers the guess is that  $k^{i,i} = \beta \frac{W^i}{q^c}$  and  $c^i = (1 - \beta)W^i$  and that their value function is of the form  $V_2^i = \psi^i(X) + \frac{1}{(1-\beta)} \log W^i$  where  $\psi^i(X)$  is, again, a function of the aggregate state.

Consider the k-producer's problem during the first stage then. Substituting the guess for  $V_2^i$  and his constraints yields:

$$\begin{aligned} V_1^i &= \max_{\mathbb{I}(\omega) \in \{0,1\}} \mathbb{E} \left[ \psi^i(X) + \log \left( \left( p \int_0^1 \mathbb{I}(\omega) d\omega + q^c \mathbb{E}[\lambda(\omega, \phi') | \omega < \omega^*(X)] \right) k \right) | X \right] \\ &= \psi^i(X) + \log k + \max_{\mathbb{I}(\omega) \in \{0,1\}} \mathbb{E} \left[ \log \left( \left( p \int_0^1 \mathbb{I}(\omega) d\omega + q^c \mathbb{E}[\lambda(\omega, \phi') | \omega < \omega^*(X)] \right) \right) | X \right] \end{aligned}$$

From this expression, we observe that choosing  $\mathbb{I}(\omega)$  is identical to choosing a cut-off  $\omega^*$  under which all units of quality lower than this cut-off are sold. This follows from the fact that a solution to the problem above can be attained by an optimal  $\mathbb{I}^*(\omega)$  which is monotone decreasing. Suppose not and assume the optimal plan is given by some  $\mathbb{I}'(\omega)$  whose value is cannot be attained by any monotone decreasing policy. It is enough to show that the producer can find another  $\mathbb{I}(\omega)$  that integrates to the same number, that is monotone decreasing and that makes his value weakly greater.

Since  $\mathbb{I}'(\omega)$  and  $\mathbb{I}(\omega)$  integrate to the same number, the amount of IOUs obtained by the k-producer during the first stage, is the same:  $p \int_0^1 \mathbb{I}(\omega) d\omega = p \int_0^1 \mathbb{I}'(\omega) d\omega$ . Now, since  $\mathbb{I}(\omega)$  is monotone decreasing and  $\lambda(\omega, \phi)$  is monotone increasing in  $\omega$ ,

$$\int [1 - \mathbb{I}'(\omega)] \lambda(\omega, \phi') d\omega \leq \int [1 - \mathbb{I}(\omega)] \lambda(\omega, \phi') d\omega$$

implying that any optimal can be attained by some  $\mathbb{I}^*(\omega)$  monotone decreasing. This implies that, as in the textbook lemons problem, solving for  $\mathbb{I}^*(\omega)$  is equivalent to choosing a threshold  $\omega^*$ . Substituting this threshold into the objective yields and expression for the optimal cutoff rule:

$$\omega^*(X) = \arg \max_{\tilde{\omega}} \mathbb{E} \left[ \log \left[ p\tilde{\omega} + q^c(X, X') \int_{\tilde{\omega}}^1 \lambda(\omega, \phi') d\omega \right] | X \right]. \quad (9)$$

This proves Proposition 3. I now return to the second stage problems. Taking the solution to (9) as given, we know that the optimal plan for an k-producers sets  $x = p(X) \omega^*(X) k$ . Using the optimal policy for  $\omega^*$  and

these definitions, one can write the second stage Bellman equation without reference to the first stage. To do this, one can substitute in for  $x$  and  $k$  in the second stage Bellman equation to rewrite the k-producer's problem as,

$$\begin{aligned} \max_{c \geq 0, i, k^b \geq 0} \log(c) + \beta \mathbb{E} [\pi V_1^i + (1 - \pi) V_1^p | X] \\ c + i + qk^b = p\omega^*(X)k \text{ and } k' = k^b + i + k \int_{\omega^*(X)}^1 \lambda(\omega, \phi') d\omega. \end{aligned}$$

Now, since  $(V_1^i, V_1^p)$  are increasing in  $k'$ , and  $k^b$  and  $i$  are perfect substitutes, an optimal solution will set  $i > 0$  only if  $q \geq 1$  and  $k^b > 0$  only if  $q \leq 1$ . This implies that substituting the k-producer's capital accumulation equation into his budget constraint simplifies his problem to:

$$\max_{c \geq 0, k'} \log(c) + \beta \mathbb{E} [\pi V_1^i(k', X') + (1 - \pi) V_1^p(k', X') | X] \text{ s.t. } c + q^c k' = w^i k.$$

The same steps allow one to write the c-producer's problem as,

$$\max_{c \geq 0, k'} \log(c) + \beta \mathbb{E} [\pi V_1^i + (1 - \pi) V_1^p | X] \text{ s.t. } c + qk' = w^p k.$$

Replacing the definitions of  $V_1^i$  and  $V_1^p$  into the objective above, and substituting our guess yields  $V_2^i$  and  $V_2^p$ , we obtain:

$$\max_{c \geq 0, k'} \log c + \frac{\beta}{(1 - \beta)} \log k' + \tilde{\psi}^i(X) \text{ s.t. } c + q^c k' = w^i k$$

and

$$\max_{c \geq 0, k'} \log c + \frac{\beta}{(1 - \beta)} \log k' + \tilde{\psi}^p(X) \text{ s.t. } c + qk' = w^p k.$$

respectively. In this expressions,  $\tilde{\psi}^i(X)$  and  $\tilde{\psi}^p(X)$  are functions of  $X$  and don't depend on the current periods choice. Taking first order conditions for  $(k', c)$  in both problems leads to:

$$\begin{aligned} c^i &= (1 - \beta) w^i(\omega^*, X) k \text{ and } k^{i,\prime} = \frac{\beta}{q^c} w^i(\omega^*, X) k \\ c^p &= (1 - \beta) w^i(X) k \text{ and } k^{p,\prime} = \frac{\beta}{q} w^p(X) k \end{aligned}$$

These solutions are consistent with the statement of Propositions 1 and 2. To verify that the guess for our value functions is the correct one, we substitute in the optimal policies:

$$\begin{aligned} & \log(1 - \beta) w^i(\omega^*, X) k + \frac{\beta}{(1 - \beta)} \log \frac{\beta}{q^c} w^i(\omega^*, X) k + \tilde{\psi}^i(X) \\ &= \frac{\log w^i(\omega^*, X) k}{(1 - \beta)} + \psi^i(X) = \frac{\log W^i(k, \omega^*, X)}{(1 - \beta)} + \psi^i(X) \end{aligned}$$

for some function  $\psi^i(X)$ . The same steps lead to a similar expression for c-producers. This verifies the initial guess.

## B.2 Proof of Lemma 4 and Proposition 5

Lemma 4 and Proposition 5 are proven jointly here. We begin by guessing that  $V_1^f(n, X) = v_1^f(X)n$ , and  $V_2^f(n, X) = v_2^f(X)n$  where  $v_2^f(X) = \beta^F \mathbb{E} \left[ v_1^f(X) R^b \right]$  if the banker remains alive and  $v_2^f(X) = \beta^F R^b n$  if he dies.

Plugging this guess into the bankers problem yields:

$$\begin{aligned} & \max_{Q \geq 0, e \in [0, \bar{e}], d \in [0, 1]} (1 - \tau) d - e + \mathbb{E} \left[ v_2^f(X') \left( \Pi(X, X') Q + n' \right) | X \right] \\ = & \max_{Q \geq 0, e \in [0, \bar{e}], d \in [0, 1]} (1 - \tau) d - e + \beta^F R^b \mathbb{E} \left[ v_1^f(X) \left( \Pi(X, X') Q + n' \right) | X \right] \end{aligned}$$

subject to,

$$\begin{aligned} -\min_{X'} \Pi(X, X') Q & \leq n' \\ n' & = n + e - d \end{aligned}$$

Assume that the optimal solution to this problem is characterized by some  $e^*(n, X)$  and  $d^*(n, X)$  to be determined. In equilibrium,  $\Pi(X, X')$  is finite. Hence,  $\mathbb{E} \left[ v_2^f(X') \Pi(X, X') \right]$  is also finite, provided that the problem has a finite solution. If  $\mathbb{E} \left[ v_2^f(X') \Pi(X, X') \right] > 0$  and  $-\min_{X'} \Pi(X, X') \leq 0$ , the banker would set  $Q^* = \infty$ . But this would imply that in equilibrium  $\Pi(X, X') \leq 0$  for any  $X'$  because there cannot be a future state where firms provide infinite intermediation and there are positive profits. Hence, it is the case that if  $\mathbb{E} \left[ v_2^f(X') \Pi(X, X') \right] > 0 \rightarrow -\min_{X'} \Pi(X, X') > 0$ . Now if this is the case,

$$Q^* = \frac{n'}{-\min_{X'} \Pi(X, X')} > 0. \quad (10)$$

If  $\mathbb{E} \left[ v_2^f(X') \Pi(X, X') \right] < 0$ , the producer optimally sets  $Q^*$ . If  $\mathbb{E} \left[ v_2^f(X') \Pi(X, X') \right] = 0$ ,  $Q^*$  is indeterminate (but finite). Thus, in either case,  $\mathbb{E} \left[ v_2^f(X') \Pi(X, X') Q^* \right] = 0$ .

This implies that for any optimal policy,

$$\mathbb{E} \left[ v_2^f(X') \Pi(X, X') Q^* \right] = \max \left\{ \frac{v_2^f(X') \Pi(X, X') n'}{-\min_{X'} \Pi(X, X')}, 0 \right\}.$$

Thus, one can substitute this expression into the objective of the firm and express it without reference to  $Q$  :

$$\begin{aligned} & \max_{e \in [0, \bar{e}], d \in [0, n]} (1 - \tau) d - e + n' \beta^F R^b \mathbb{E} \left[ v_2^f(X') + \max \left\{ \frac{v_2^f(X') \Pi(X, X')}{-\min_{X'} \Pi(X, X')}, 0 \right\} | X \right] \\ = & \max_{e \in [0, \bar{e}], d \in [0, n]} (1 - \tau) d - e + (n + e - d) \beta^F R^b \mathbb{E} \left[ v_2^f(X') + \max \left\{ \frac{v_2^f(X') \Pi(X, X')}{-\min_{X'} \Pi(X, X')}, 0 \right\} | X \right] \end{aligned}$$

where the second line uses the definition of  $n'$ . Now, it is clear from this expression that any optimal financial

policy satisfies,

$$\begin{aligned} e &> 0 \text{ only if } \beta^F \left[ \mathbb{E}[v_2^f(X')] + \max \left\{ \frac{\mathbb{E}[v_2^f(X')\Pi(X, X')]}{-\min_{\tilde{X}} \Pi(X, \tilde{X})}, 0 \right\} \right] \geq 1 \\ d &> 0 \text{ only if } \beta^F \left[ \mathbb{E}[v_2^f(X')] + \max \left\{ \frac{\mathbb{E}[v_2^f(X')\Pi(X, X')]}{-\min_{\tilde{X}} \Pi(X, \tilde{X})}, 0 \right\} \right] \leq (1 - \tau). \end{aligned}$$

If the inequalities are strict, it is clear that,  $e = \bar{e}$  and  $d = n$ . By linearity,  $e$  and  $d$  are indeterminate when the relations hold with equality, and equal 0 if these are not satisfied. By assumption  $e = \bar{e}$  is never binding. If  $d = n$ , for some state,  $d$  is linear in  $n$ . This implies that  $e(n, X) = e^*(X)n$ ,  $d(n, X) = d^*(X)n$  are solutions to the producer's problem.

We now use this results to show that the value function is linear in  $n$ . Plugging in the optimal policies into the objective we obtain:

$$\left[ (1 - \tau) d^*(X) - e^*(X) + (1 + e^*(X) - d^*(X)) \beta^F R^b \mathbb{E} \left[ v_2^f(X') + \max \left\{ \frac{v_2^f(X') \Pi(X, X')}{-\min_{X'} \Pi(X, X')}, 0 \right\} | X \right] \right] n$$

which is a linear function of  $n$ .

Returning to the optimal quantity decision, then it is clear that  $Q$  can be written as,

$$Q = \frac{1 + e^*(X) - d^*(X)}{-\min_{X'} \Pi(X, X')} n =: Q^*(X) n.$$

and clearly,  $Q^*(X) = \arg \max_{\tilde{Q}} \mathbb{E} [v_2^f(X') \Pi(X, X') | X] \tilde{Q}$  subject to  $\Pi(X, X') \tilde{Q} \leq n'$ . This proves, Proposition 6.

We are ready to show that  $v_1^f(X)$  solves a functional equation. Define

$$\tilde{v}(X) = \beta^F R^b \mathbb{E} \left[ v_2^f(X') + v_2^f(X') \max \left\{ \frac{\Pi(X, X')}{-\min_{X'} \Pi(X, X')}, 0 \right\} | X \right]$$

as the marginal value of equity in the bank and note that:

$$v_1^f(X) = \max_{d^*(X) \in [0, 1], e \geq 0} (1 - \tau) d^*(X) - e^*(X) + (1 + e^*(X) - d^*(X)) \tilde{v}(X).$$

If  $\tilde{v}(X) \in ((1 - \tau), 1)$ , then  $v_1^f(X) = \tilde{v}(X)$  because  $(d^*(X), e^*(X)) = 0$ . If  $\tilde{v}(X) \leq (1 - \tau)$ , then  $e^*(X) = 0$  and we have that,

$$(1 - \tau) d^*(X) + (1 - d^*(X)) \tilde{v}(X) = (1 - \tau).$$

Finally, if  $\tilde{v}(X) = 1$ , then,  $v_1^f(X) = 1$ . This information is summarized in the following functional equation for  $v_1^f(X)$ :

$$v_1^f(X) = \min \left\{ \max \left\{ \beta^F R^b \mathbb{E} \left[ v_2^f(X') \left\{ 1 + \max \left\{ \frac{\Pi(X, X')}{-\min_{X'} \Pi(X, X')}, 0 \right\} \right\} | X \right], (1 - \tau) \right\}, 1 \right\}$$

which equals,

$$\min \left\{ \max \left\{ \mathbb{E} \left[ \left( \rho + (1 - \rho) v_1^f(X'') \right) \beta^F R^b \left\{ 1 + \max \left\{ \frac{\Pi(X, X')}{-\min_{X'} \Pi(X, X')}, 0 \right\} \right\} | X \right], (1 - \tau) \right\}, 1 \right\}.$$

This functional equation determines the slope of the bankers value function,  $v_1^f(X)$ . It can be shown that the solution to this functional equation is unique. Assumptions 9.18-9.20 of [Stokey et al. \(1989\)](#) are satisfied by this problem. It remains to show that Assumption 9.5 (part a) is also satisfied. By assumption,  $X$  is compact so the only piece left is that  $X$  is countable. Because the transition function for the state is an endogenous object, as it depends on an aggregate state,  $\kappa$ . It will be shown that although (d,e) are not uniquely defined, there is unique mapping from  $\phi$  to  $\kappa'$ . By exercise 9.10 in [Stokey et al. \(1989\)](#), together, these assumptions ensures that there is a unique solution to the this functional equation.

### B.3 Proof increasing $p(x)$

Let  $q(X, X')$ , is the market price that solves the market clearing condition given a price under asymmetric information of  $p$ . In equilibrium, this price is a function of the previous state,  $p(X)$ . Thus, through the equilibrium price  $p(X)$ ,  $q(X, X')$  defines an equilibrium  $q$ , implicitly, as function of the current state  $X'$  and the previous state  $X$ :  $q(X', X) \equiv \tilde{q}(p(X), X')$ . Given,  $X$ , and the law of motion for  $X'$ ,  $\tilde{q}(X', X)$  determines the profits for the financial sector given and amount of trade.

*Proof.* To characterize the key objects  $Q(X)$ ,  $p(X)$  and  $q(X)$ . we need some we need to define some objects. The supply for financial contracts is  $Q^s(p, X) = \tilde{\omega}(p, X) \kappa$  and  $Q^d = \{[]$  and  $\tilde{\Pi}(p, X') = \tilde{q}(p, X') \mathbb{E}_{\phi'}[\lambda(\omega) | \omega > \bar{\omega}(p, X)]$ . I provide some further characterization of this supply.

$$Q_p^s > 0, Q^s(0, X) = 0$$

and

$$Q^s(\mathbb{E}[q^c(X') \mathbb{E}_{\phi'}[\lambda(\omega)]] , X) = k.$$

Thus, the supply schedule is invertible and bounded, and thus, we define:

$$P(Q) \equiv p \text{ such that } Q^s(p, X) = Q$$

and

$$P_Q(Q) > 0, P(0) = 0 \text{ and } P(X) = \mathbb{E}[q^c(X') \mathbb{E}_{\phi'}[\lambda(\omega)]]$$

This proposition establishes the existence of a well behaved supply function:  $P(Q)$  is bounded, differentiable and increasing.  $\square$

### B.4 Proof of Proposition 6

To pin down  $q$ , fix any sequence of states  $(X, X')$ , and let  $\bar{\omega} = \omega(X)$ . We begin the proof assuming  $q > 1$  so that  $D^i = 0$ . Market clearing in stage 2 requires  $D^p(X, X') = S(X) = \mathbb{E}[\lambda(\omega, \phi') | \omega \leq \bar{\omega}] \bar{\omega} \pi K$ . By Proposition 1, we can integrate across the c-producer's policy functions to obtain an expression for  $D^p(X, X')$  as a function of  $q$ :

$$\beta \int \left[ \frac{W^p(k, x, X)}{q} - \bar{\lambda}(\phi') k \right] \Gamma^c(dk) = \beta \frac{A + q\bar{\lambda}(\phi')}{q} (1 - \pi) K$$

By market clearing,  $q$  be such that:

$$\left[ \beta \frac{A + q\bar{\lambda}(\phi')}{q} - \bar{\lambda}(\phi') \right] (1 - \pi) K = \mathbb{E} [\lambda(\omega, \phi') | \omega \leq \bar{\omega}] \bar{\omega} \pi K.$$

Manipulating this expression leads to the value of  $q$  that satisfies market clearing:

$$q = \frac{\beta A (1 - \pi)}{\mathbb{E} [\lambda(\omega, \phi') | \omega \leq \bar{\omega}] \bar{\omega} \pi + (1 - \pi) (1 - \beta) \bar{\lambda}(\phi')}$$

Recall now that this expression is valid only when  $q > 1$ , because capital good producer's are not participating in the market. Thus, the expression is only true for value of

$$\beta A \left[ \frac{\pi}{(1 - \pi)} \mathbb{E} [\lambda(\omega, \phi') | \omega \leq \bar{\omega}] \bar{\omega} + (1 - \beta) \bar{\lambda}(\phi') \right]^{-1} > 1. \quad (11)$$

If  $q = 1$ , then it must be the case that the total demand for capital must be larger than the supply provided by financial firms.  $D^i(X, X')$  in this case is obtained also by integrating across the demand for capital of  $k$ -producer's given in Proposition 1. Thus, for a stage one price  $p$ , this demand is given by

$$D^i + I = \beta p \bar{\omega} \pi K - (1 - \beta) \mathbb{E} [\lambda(\omega, \phi') | \omega \leq \bar{\omega}] (1 - \bar{\omega}) \pi K \text{ for } q = 1$$

The corresponding condition is that,

$$\beta p \bar{\omega} - (1 - \beta) \mathbb{E} [\lambda(\omega, \phi') | \omega \leq \bar{\omega}] (1 - \bar{\omega}) \pi + [\beta A - (1 - \beta) \bar{\lambda}(\phi')] (1 - \pi) \geq \pi \mathbb{E} [\lambda(\omega, \phi') | \omega \leq \bar{\omega}] \bar{\omega} \quad (12)$$

where, the aggregate capital stock has been canceled from both sides. If the condition is satisfied, then  $q = 1$ , and

$$D^i(q, p) = \pi \mathbb{E} [\lambda(\omega, \phi') | \omega \leq \bar{\omega}] \bar{\omega} - [\beta A - (1 - \beta) \bar{\lambda}(\phi')] (1 - \pi)$$

and

$$I = [\beta p \bar{\omega} - (1 - \beta) \mathbb{E} [\lambda(\omega, \phi') | \omega > \bar{\omega}] (1 - \bar{\omega})] \pi - D^i(q, p)$$

If (11) and (12) are violated, this implies  $q < 1$  and that  $I = 0$ . The corresponding market clearing condition is obtained by solving  $q$  from:

$$\begin{aligned} & \left[ \frac{\beta p \bar{\omega}}{q} - (1 - \beta) \mathbb{E} [\lambda(\omega, \phi') | \omega > \bar{\omega}] (1 - \bar{\omega}) \right] \pi + \left[ \frac{\beta A}{q} - (1 - \beta) \bar{\lambda}(\phi') \right] (1 - \pi) \\ & \geq \pi \mathbb{E} [\lambda(\omega, \phi') | \omega < \bar{\omega}] \bar{\omega}. \end{aligned}$$

We can collect the terms where  $q$  shows in the denominator to obtain,

$$\frac{\beta (p \bar{\omega} \pi + A)}{q} = \pi \mathbb{E} [\lambda(\omega, \phi') | \omega < \bar{\omega}] \bar{\omega} + (1 - \beta) [-\mathbb{E} [\lambda(\omega, \phi') | \omega < \bar{\omega}] \bar{\omega} \pi + \bar{\lambda}(\phi')]$$



The solution is given by:

$$q = \frac{\beta (\pi p^i \bar{\omega} + A)}{(\beta \mathbb{E} [\lambda (\omega, \phi') | \bar{\omega} < \bar{\omega}] \bar{\omega} \pi + (1 - \beta) \bar{\lambda} (\phi'))}$$

The formula in Proposition 6 corresponds. . Moreover, the demand function is weakly decreasing so for each  $p, X$  there will be a unique  $q$  satisfying the market clearing condition.

From (??) we observe that the shock affects the  $\tilde{q}(X', X)$  and  $\mathbb{E} [\lambda (\omega, \phi') | \omega < \bar{\omega}]$ . From Proposition (??), we can express the profit function in the following way:

$$\Pi (X, X') = \max \left\{ (1 - \pi) \beta A \frac{\pi \mathbb{E}_{\phi'} [\lambda (\omega) | \bar{\omega} < \bar{\omega}] \bar{\omega}}{\pi \mathbb{E} [\lambda (\omega, \phi') | \bar{\omega} < \bar{\omega}] \bar{\omega} + (1 - \beta) \bar{\lambda} (\phi')}, \tilde{\pi}(X, X') \right\}$$

where

$$\tilde{\Pi}(X, X') = \min \left\{ 1, (\pi p^i + A (1 - \pi)) \frac{\pi \mathbb{E} [\lambda (\omega, \phi') | \bar{\omega} < \bar{\omega}] \bar{\omega}}{\left( \frac{(1-\beta)\lambda}{\beta} + \pi \bar{\omega} \mathbb{E} [\lambda (\omega, \phi') | \bar{\omega} < \bar{\omega}] \right)} \right\}$$

Since both functions are increasing in  $\mathbb{E} [\lambda (\omega, \phi') | \omega < \bar{\omega}]$  in the conditional expectation, we know by Assumption **A1**, that this functions are decreasing in the shock  $\phi'$ . Thus,  $\Pi (X, X')$  is decreasing in  $\phi'$ .

## B.5 Proof of monotone relation between $\kappa$ and $\omega$

Observe that  $\mathbb{E} [\Pi (X', p) - p] > 0$ , is continuous in  $p$ . Thus, there is a sufficiently small  $\varepsilon > 0$  increase in  $p$  such that the inequality still holds. Since the inequality implies that capacity constraints bind in equilibrium, then, market clearing implies that there exists some  $\epsilon(\varepsilon)$ , such that  $p(X) + \varepsilon = P \left( \frac{s(\kappa + \epsilon(\varepsilon))}{\pi(p(X) + \varepsilon, X'_{\min})} \right)$ . In an un-improvable, it must be the case that  $\pi \left( p(X) + \varepsilon, X'_{\min} \right)$  is decreasing, because otherwise there would have existed a larger equilibrium with a higher price. Thus,  $\epsilon(\varepsilon)$  must increase. This, implies that for a given  $\kappa$ , we can find a small enough increase in  $\kappa$ , so that the equilibrium price increase.

If  $\mathbb{E} [\Pi (X', p) - p] = 0$  and constraint does not bind, then, there is always a small enough increase in  $\kappa$ , such that capacity constraints don't bind, and therefore, the equilibrium price remains constant. If  $\mathbb{E} [\Pi (X', p) - p] = 0$  and capacity constraints bind, then increase in  $\kappa$  will relax the binding constraint. Either  $Q$  remains the same or increases. Thus,  $p$  must increase.

## B.6 Proof of efficiency

*Proof.* The necessary condition:  $(1 - \tau_d) \leq \beta^F R^b$ . Suppose not, then for any state  $\Pi (X', X) = 0$ , then, it is convenient to pay dividends.

$$\begin{aligned} \tilde{v}(X) &= \beta^F R^b \left[ \mathbb{E}[\tilde{v}(X')] + \max \left\{ \frac{\mathbb{E}[\tilde{v}(X') \Pi(X, X')]}{-\min_{\tilde{X}} \Pi(X, \tilde{X})}, 0 \right\} \right] \\ &< \beta^F R^b \left[ \mathbb{E}[\tilde{v}(X')] + \max \left\{ \frac{\mathbb{E}[\Pi(X, X')]}{-\min_{\tilde{X}} \Pi(X, \tilde{X})}, 0 \right\} \right] \\ &= \beta^F R^b \mathbb{E}[\tilde{v}(X')] \\ &< \beta^F R^b \end{aligned}$$

where the first line follows from the definition of  $\tilde{v}(X)$  and  $v_2^f$ , the second follows from the fact that  $\tilde{v}(X') \leq 1$  and the third from the assumption that an efficient equilibrium satisfies  $\mathbb{E}[\Pi(X, X')] = 0$  and the last inequality uses  $\tilde{v}(X') \leq 1$  once more. Then, if the condition is not satisfied,  $\tilde{v}(X) < \beta^F R^b < (1 - \tau_d)$ . This fact in turn implies that any state with financial risk capacity  $\kappa$  consistent with efficient intermediation is reflected to another state with  $\mathbb{E}[\Pi(X, X')] > 0$ .

The sufficient condition is obtained reversing the equalities.

$$\begin{aligned}\tilde{v}(X) &= \beta^F R^b \left[ \mathbb{E}[\tilde{v}(X')] + \max \left\{ \frac{\mathbb{E}[\tilde{v}(X') \Pi(X, X')]}{-\min_{\tilde{X}} \Pi(X, \tilde{X})}, 0 \right\} \right] \\ &> \beta^F R^b \left[ \mathbb{E}[\tilde{v}(X')] + \max \left\{ \frac{(1 - \tau_d) \mathbb{E}[\Pi(X, X')]}{-\min_{\tilde{X}} \Pi(X, \tilde{X})}, 0 \right\} \right] \\ &> \beta^F R^b \mathbb{E}[\tilde{v}(X')]\end{aligned}$$

The first line follow from the definition of  $\tilde{v}(X)$ . The second uses that  $(1 - \tau_d) \tilde{v}(X)$  has an upper bound. The third uses The hypothesis that  $\mathbb{E}[\Pi(X, X')] = 0$ . With this inequality, it is enough to argue that there will always exist some  $\kappa$  such that  $\mathbb{E}[\tilde{v}(X')]$  is sufficiently above  $(1 - \tau_d)$  such that state is not reflected.  $\square$

## C Data Appendix

**Capital, Output and Investment Time Series.** The estimate for the capital stock and the output of the U.S. economy is constructed from the series on Gross Private Non-Residential Fixed Investment (PNFI), Gross Private Residential Fixed Investment (PRFI), and Consumption of Fixed Capital (COFC) series reported by the U.S. Department of Commerce and the Bureau of Economic Analysis. Both investment series were added and the consumption of fixed capital was subtracted to account for the depreciation of capital. The initial capital stock was taken so that the investment to capital ratio changes the least as possible.

The series for Total Factor Productivity (TFP) was reconstructed by dividing Gross domestic product (GDP) by the capital stock and correcting by the Implicit Price Deflator (GDPDEF). I estimated an AR(1) process for TFP using ordinary least squares. The sample starts in 1970Q1 and ends in 2010Q4.

**Banking Time Series.** I use the Federal Reserve Bank of Chicago dataset on bank holding company collected from the FRY-9 regulatory reports. These reports contain balance sheet, income information and risk-based capital measures. I used balance sheet and income information from the the largest fifty bank holding companies in terms of their assets. The data items are available in the Wharton Research Database Services (WRDS). Table 5 summarizes the variables used and their equivalences.

The numbers in parenthesis correspond to the RSSD-identification number of each institution. Companies in bold are those that were excluded to isolate the effect of large mergers and acquisitions. The companies included in the sample are:

BANK OF AMERICA CORPORATION (1073757), **JPMORGAN CHASE & CO. (1039502)**, CITI-GROUP INC. (1951350), **WELLS FARGO & COMPANY (1120754)**, **GOLDMAN SACHS GROUP, INC., THE (2380443)**, MORGAN STANLEY (2162966), METLIFE, INC. (2945824), TAUNUS CORPORATION (2816906), HSBC NORTH AMERICA HOLDINGS INC. (3232316), U.S. BANCORP (1119794), BANK OF NEW YORK MELLON CORPORATION, THE (3587146), PNC FINANCIAL SERVICES GROUP, INC., THE (1069778), CAPITAL ONE FINANCIAL CORPORATION (2277860), TD BANK US HOLD-

Model Variable	FR Y-9 Report Item	Variable Meaning
Deposits / Loans	bhck2122	C&I + real estate + leases + consumer loans
Loans + Interest Income	bhck2122+bhck4107	Loans+ net interest income
Net Interest	bhck4074	Net interest income
Equity	bhck3230-(bhck3163+bhck0426+bhck2148)	Tangible net-worth
Fixed costs	bhck4217+bhck4135	Average non interest net-expenses
Dividends	bhck4340-bhck3247	Earnings - retained earnings
Equity Injections	bhck3210-bhck3217	Net Change in common equity

Table 5: **Data and Model equivalences.**

ING COMPANY (1249196), STATE STREET CORPORATION (1111435), **ALLY FINANCIAL INC. (1562859)**, SUNTRUST BANKS, INC. (1131787), BB&T CORPORATION (1074156), **AMERICAN EXPRESS COMPANY (1275216)** CITIZENS FINANCIAL GROUP, INC. (1132449), REGIONS FINANCIAL CORPORATION (3242838), FIFTH THIRD BANCORP (1070345), NORTHERN TRUST CORPORATION (1199611), KEYCORP (1068025), RBC USA HOLDCO CORPORATION (3226762), UNION-BANCAL CORPORATION (1378434), M&T BANK CORPORATION (1037003), HARRIS FINANCIAL CORP. (1245415), BANCWEST CORPORATION (1025608), **DISCOVER FINANCIAL SERVICES (3846375)** BBVA USA BANCSHARES, INC. (1078529), COMERICA INCORPORATED (1199844), HUNTINGTON BANCSHARES INCORPORATED (1068191), ZIONS BANCORPORATION (1027004), UTRECHT-AMERICA HOLDINGS, INC. (2307280), **CIT GROUP INC. (1036967)** MARSHALL & ILSLEY CORPORATION (3594612), NEW YORK COMMUNITY BANCORP, INC. (2132932), POPULAR, INC. (1129382), FIRST NIAGARA FINANCIAL GROUP, INC.(2648693), SYNOVUS FINANCIAL CORP. (1078846), FIRST HORIZON NATIONAL CORPORATION (1094640), BOK FINANCIAL CORPORATION (1883693), CITY NATIONAL CORPORATION (1027518), ASSOCIATED BANC-CORP (1199563), EAST WEST BANCORP, INC. (2734233), FIRST CITIZENS BANCSHARES, INC. (1075612), COMMERCE BANCSHARES, INC. (1049341), TCF FINANCIAL CORPORATION (2389941), WEBSTER FINANCIAL CORPORATION (1145476).