Debt-Overhang Banking Crises

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This paper studies how a worsening of the debt overhang distortion on bank lending can explain banking solvency crises that are accompanied by a plunge of bank asset values and by a severe contraction of lending and economic activity. Since the value of bank assets depends on economic prospects, a pessimistic view of the economy can be self-fulfilling and can trigger a financial crisis: If economic prospects are poor, bank asset values decline, the bank risk of default rises, and the associated debt overhang distortion worsens. The worsening of the distortion leads to a contraction in bank loans and a decline in economic activity, which confirms the initial pessimistic view. Signals of the existence of systemic risk include: a rise in the volatility and the presence of two modes in the probability distribution functions of the returns of bank-issued bonds and of portfolios of bank-issued bonds and equities; and a surge in the correlation between bank-issued bond returns. Macroprudential policy should limit the sensitivity of bank balance sheets to the aggregate economy and to the financial sector, using investment restrictions, capital requirements, and stress tests. In the event of a crisis, policy options include reducing the above sensitivity with commitments and guarantees, stimulating the economy, and restructuring bank capital and ownership.

Filippo Occhino is at the Federal Reserve Bank of Cleveland and can be reached at filippo.occhino@clev.frb.org. He thanks Aleksander Berentsen, Ellis Tallman, and seminar participants at the Swiss National Bank.

1   Introduction

Some of the most severe contractions of economic activity are accompanied by banking crises.[1] In a typical economic and banking crisis, bank asset values drop, a large number of banks default or become insolvent, bank lending and economic activity contract. The period of economic weakness and banking stress tends to be prolonged. The change in economic fundamentals appears small relative to the severity of the financial and economic effects.

To study this type of economic and banking crisis, we model a mechanism based on Myers' debt overhang distortion on bank lending.[2] Two features of the banking system play an important role: the liabilities of banks distort their lending choices, inducing them to lend less than the optimal amount of funds; and the value of bank assets is sensitive to economic prospects. Because of these two features, a pessimistic view of the economy can become self-fulfilling and can trigger a financial crisis: If the economy is expected to perform poorly, then the value of bank assets declines, the bank risk of default rises, and the associated debt overhang distortion worsens; this leads to a contraction in bank lending and a decline in economic activity, which confirms the initial pessimistic view (see Figure 1). In this mechanism, the fragility of the banking system results from the interaction between the loan-granting activity of banks and the sensitivity of

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[1]In the U.S., the recessions that were accompanied by banking crises—the ones that began in 1873, 1893, 1907, 1929, and 2007—were all especially severe (Bordo and Haubrich 2010, Table 1 and Figure 1). During the Great Depression, in particular, the rise of bank failures and the fall of bank loans in the years 1930-1933 were decisive in making the recession so deep and so long (Bernanke 1983).

[2]Myers (1977) is the seminal article that describes how the existing debt of firms discourages their investment. The marginal cost of a firm's new investment is borne by the equity holders (or by junior creditors). The marginal return, however, is seized by the senior creditors in the event of default. The higher the firm's probability of default, the lower the equity-holders' expected marginal return, the smaller their incentive to invest, the lower the investment level. The investment level is sub-optimal because the equity holders do not internalize the positive effect of the new investment on the senior creditors' payoff. In the case of banks, their existing liabilities discourage their lending.
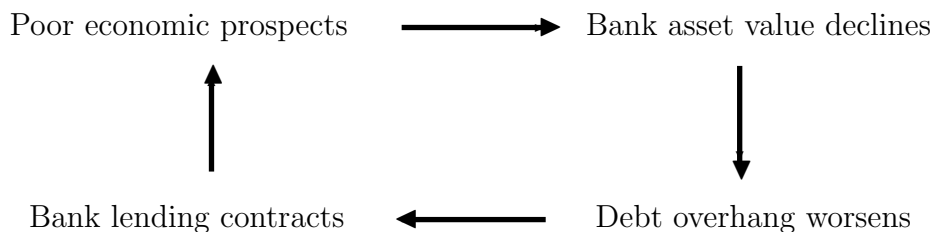
Figure 1: Debt-overhang mechanism.

their assets to aggregate economic conditions—no role is played by the deposit-receiving activity of banks and by the liquidity mismatch between their assets and liabilities, which instead are crucial in standard models of financial fragility.

This debt-overhang mechanism can explain a variety of economic and banking crises where a rise in the risk of default of the banking sector is accompanied by the fall of asset values sensitive to economic activity. One example is a banking crisis associated with a crash of markets for financial securities, including equities, bonds, asset-backed securities and derivatives. Another example is a crisis associated with a sovereign default. If banks invest in government bonds, then the economy is vulnerable to a debt-overhang financial crisis where economic activity declines, the tax revenue drops, the government defaults, the banks' balance sheets weaken, and the debt overhang distortion rises and discourages lending. A final example is an economic and banking crisis associated with a currency crisis. If bank assets are denominated in the local currency, while bank liabilities are denominated in a foreign currency, and if the exchange value of the local currency depends on local economic activity, then the economy is vulnerable to a debt-overhang financial crisis where economic activity declines, the currency depreciates, bank balance sheets weaken, and the debt overhang distortion rises and discourages lending. The mechanisms in the latter two examples may reinforce each other in the case of an emerging market economy where government bonds are issued in a foreign currency.

In the rest of the paper, Section 2 reviews the literature; Section 3 introduces the model and describes the debt-overhang mechanism; Section 4 shows that this mechanism can give rise to a financial crisis; Section 5 investigates how systemic risk can be detected and measured; Section 6 studies the policies that can be implemented to reduce or eliminate the systemic risk and to contain the effects of a crisis; Section 7 concludes.

2   Two strands of literature

This paper is most closely related to the growing literature on the aggregate implications of debt overhang. Lamont (1995) shows that multiple equilibria can arise when firms' investments are distorted by debt overhang and have positive spillovers, i.e. the net present value of investing depends positively on other firms' investment. Philippon (2009) studies how the interaction of debt overhang in multiple markets can amplify shocks and even lead to multiple equilibria, and how governments can improve efficiency through bailouts and other policies during the renegotiation of the debt contract. Occhino and Pescatori (2010) introduce debt overhang in an otherwise standard business cycle framework, and evaluate quantitatively the resulting amplification and propagation mechanisms of shocks. Arellano, Bai and Kehoe (2012) use a model where debt overhang discourages labor to replicate the dynamics of labor, output and labor productivity during the Great Recession. Occhino and Pescatori (2014) and Gomes, Jermann and Schmid (2013) study monetary policy when firms issue nominal debt, and find that unanticipated increases of inflation reduce the real value of firms' liabilities and reduce the corporate debt overhang, and that the monetary authority should raise inflation in response to adverse shocks. Kobayashi and Nakajima (2014) describe a different debt overhang mechanism that can generate multiple equilibria: Suppose firms have long-term debt and need short-term liquidity to produce; The expected return on a short-term loan provided by a depositor depends positively on the total amount of short-term liquidity provided by other depositors, because the latter decreases the default probability; This makes the economy vulnerable

to a liquidity crisis equilibrium where no depositor provides short-term loans.

More recently, the literature has shifted its focus on the debt overhang distortion in the banking sector. Wilson and Wu (2010) and Wilson (2012) study how to efficiently recapitalize banks when bank lending is distorted by debt overhang, and show that purchases of preferred stock are less efficient than purchases of common stock or bank assets. Philippon and Schnabl (2013) introduce a financial contagion mechanism that is similar to the one at work in this paper. When a bank's risk of default rises, the debt overhang distortion rises, and this induces the bank to contract its loans; at the aggregate level, this reduces payments to households, increases household defaults and raises the risk of default of other banks. They emphasize that this mechanism creates a negative externality, which renders the resulting equilibrium inefficient, and study how a government should optimally intervene with a recapitalization program. Bhattacharya and Nyborg (2013) also study optimal government recapitalization of banks that suffer from debt overhang problems. Banks have private information about the quality of their assets-in-place and new investment opportunities. Menus of bailout plans, made of equity injections and asset buyouts, are used as a screening device. Although they include the possibility of public benefits to bailouts in their analysis, they do not explicitly model cross-spillover effects. Finally, in their analysis of the objectives and tools of macroprudential regulation, Hanson, Kashyap and Stein (2013) point out that the debt overhang problem prevents banks from raising the socially-optimal amount of capital during a crisis, and leads them to shrink their assets and balance sheets excessively, which creates the need for policy intervention.

This paper is also related to the vast literature that studies the various causes and mechanics of financial crises. A crisis may be caused by an aggregate risk to which banks are commonly exposed due to their business model.[3] More often, the main driver is a contagion mechanism that amplifies the effects of a small shock to economic fundamentals or generates a self-fulfilling expectations crisis. The

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[3]Farhi and Tirole (2012) point out that banks may *choose* to be exposed to the same aggregate risk because they anticipate that the government will bail them out if that risk will materialize, threatening to generate a financial crisis.

contagion mechanism may transmit liquidity risk—since banks' assets are longer term than their liabilities, banks are vulnerable to bank runs, and a run on an individual bank can trigger runs on other banks, and precipitate a bank panic.[4] Or the contagion mechanism may transmit solvency risk, as it does in our debt-overhang model. The contagion mechanism may be direct: For instance, if banks lend to each other or invest in each other's equity, a rise in the risk of default of a bank lowers the value of the other banks' claims to that bank, and raises directly their risk of default. (Rochet and Tirole 1996). More often, the contagion mechanism has two parts: first, a rise in the risk of default of a bank induces it to reduce its asset holdings, i.e. to sell its securities or to reduce its loans; second, the decision to disinvest by a bank reduces the return on other banks' investment, and raises their risk of default.[5]

3   Model

To describe the debt-overhang contagion mechanism, we use a two-period model with a continuum of representative households, and a continuum of representative banks. Each household owns one share of each bank.

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[4]There are several helpful reviews of the literature on banking liquidity crises, including Goodhart and Illing 2002, Introduction, Allen and Gale 2008, Introduction, and Freixas and Rochet 2008, Chapter 7.

[5]An example of a two-leg mechanism is the following. If banks target a constant leverage ratio for risk-management or regulatory purposes, or a pro-cyclical one as in Adrian and Shin (2013), an initial loss at a bank induces that bank to de-leverage and sell its assets; if those assets are not perfectly liquid, this depresses their price and generates losses at other banks holding the same assets. Another example, based on the one described by Lagunoff and Schreft (2001), works as follows: an initial portfolio loss induces a bank to disinvest; this lowers the return of other banks investing in the same portfolio because the return on a bank loan depends positively on whether other banks continue to finance that project, or because it depends on aggregate economic activity which in turn depends on other banks's lending decisions.

Banks

The two key features for the debt-overhang contagion mechanism are that banks'
loans are distorted by the overhang of the existing bank liabilities and that the
value of banks' assets is sensitive to the aggregate economic activity. To model
these two features, we assume that each bank, initially, has financial liabilities
(e.g. deposits, interbank loans, long-term bonds) with face value b due at the
end of the second period, and owns financial assets (e.g. equity, corporate and
government bonds, asset-backed securities, previously granted loans) promising a
payoff $\pi(Y)$ at the end of the second period that is strictly increasing in Y, the
aggregate output produced with loans.[6] Each bank also owns an amount of liquid
funds m.

In the first period, each bank distributes dividends d_1 to households and grants
new loans l, subject to the constraint $d_1 + l = m$. Banks do not take any other
decision.

In the second period, loans are used for production. The output produced with
each individual bank's loans l is $y \equiv \omega f(l)$, where ω is a log-normally distributed
idiosyncratic shock, and $f(l) \equiv Al^\alpha$ is a production function, with $A > 0$, and
$\alpha \in (0, 1)$. Aggregate output is simply $Y \equiv E\{y\} = E\{\omega\}f(l)$, where E is the
expectation over the idiosyncratic shock ω. There is no aggregate uncertainty, so
aggregate output Y is non-stochastic.

Each bank receives the all output, y, in return of its loans.[7] It also receives the
return $\pi(Y)$ on its assets. If the sum of the two is less than the face value of its
liabilities, $y + \pi(Y) < b$, then the bank defaults, repays $y + \pi(Y)$ to the creditors,
and does not distribute any dividend. Otherwise, the bank repays the entire

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[6]As in most of the debt-overhang literature, including the two closely related papers of Lam-
ont (1995) and Philippon and Schnabl (2013), we examine the economic implications of a given
capital structure, without explaining it.

[7]To focus on the main mechanism, we lumped the financial and production sectors together.
The mechanism, however, does not depend on this assumption and would be at work even if
firms were modeled separately, banks received only a share of the output produced, and firms
distributed the rest to households or to banks as dividends.

face value b to the creditors and distributes the rest, $y + \pi(Y) - b$, as dividends. The debt payoff to the creditors is, then, $\min(y + \pi(Y), b)$ and dividends are $d_2 = y + \pi(Y) - \min(y + \pi(Y), b) = \max(y + \pi(Y) - b, 0)$.

Notice that all decisions are taken before the realization of the idiosyncratic shock ω, and banks are ex-ante identical, so all banks make the same decision. Ex-post, however, banks are heterogeneous, and this implies that some will default and some will not.

Because of the crucial role played by the sensitivity of the asset payoff $\pi(Y)$ to aggregate output, we add some more specific assumptions about the assets held by banks. Each bank holds a portfolio of three types of financial assets: $\bar{a} \geq 0$ units of a risk-free asset with unit payoff; $a_Y \geq 0$ units of an asset promising a payoff equal to $\bar{Y} + \tau(Y - \bar{Y})$, where $\bar{Y} > 0$ is a constant level of output and $\tau > 0$; and $a_V \in [0, 1)$ units of an asset promising a payoff equal to the value $V(Y) = Y + \pi(Y)$ of the representative bank in the second period. The latter can be thought of as a portfolio of equity and liabilities of the representative bank, and represents cross-participations and interbank lending. The bank's asset payoff is then

$$\pi(Y) = \bar{a} + a_Y[\bar{Y} + \tau(Y - \bar{Y})] + a_V V(Y)$$

$$\pi(Y) = \bar{a} + a_Y[\bar{Y} + \tau(Y - \bar{Y})] + a_V[Y + \pi(Y)]$$

$$\pi(Y) = \frac{\bar{a} + a_Y[\bar{Y} + \tau(Y - \bar{Y})] + a_V Y}{1 - a_V}$$

$$\pi(Y) = \bar{\kappa} + \kappa_Y Y \tag{1}$$

where $\bar{\kappa} \equiv \frac{\bar{a} + a_Y(1-\tau)\bar{Y}}{1 - a_V}$ and $\kappa_Y \equiv \frac{a_Y\tau + a_V}{1 - a_V}$.

Households

The households' objective function is

$$u(c_1) + \beta u(c_2)$$

where $\beta \in (0, 1)$, the utility function satisfies $u'(c) \equiv c^{-\gamma}$, with $\gamma > 0$, and c_1 and c_2 are the non-stochastic consumption levels in the two periods.

Households don't take any decision. They enter the first period holding the opposite financial position of banks: a short position in the financial assets held by banks, and claims to the banks' liabilities.

In the first period, they receive an endowment e_1 and banks' dividends d_1, so their first-period consumption is

$$c_1 = e_1 + d_1$$

$$c_1 = e_1 + m - l$$

In the second period, they receive an endowment e_2, they pay the financial assets' payoff $\pi(Y)$ to banks, and they receive dividends $E\{d_2\}$ and debt payoff $E\{\min(y + \pi(Y), b)\}$ from banks. Their consumption in the second period is

$$c_2 = e_2 - \pi(Y) + E\{d_2\} + E\{\min(y + \pi(Y), b)\}$$

$$c_2 = e_2 - \pi(Y) + E\{\max((y + \pi(Y) - b, 0)\} + E\{\min(y + \pi(Y), b)\}$$

$$c_2 = e_2 - \pi(Y) + E\{y + \pi(Y)\}$$

$$c_2 = e_2 + E\{y\}$$

$$c_2 = e_2 + Y$$

Bank problem

Each bank is owned by the representative household, so it makes its choices to maximize the representative household's objective function, discounting the future using the (non-stochastic) discount factor $\Lambda \equiv \beta u'(c_2)/u'(c_1)$. The following is the bank's problem:

$$\max_{d_1, l, d_2} \{d_1 + \Lambda E\{d_2\}\} \tag{2}$$

$$\text{subject to: } d_1 + l = m$$

$$d_2 = \max((y + \pi(Y) - b, 0)$$

$$\text{where } y \equiv \omega f(l)$$

The first-order condition is

$$\Lambda \frac{\partial E\{\max(\omega f(l) + \pi(Y) - b, 0)\}}{\partial l} = 1$$

$$\Lambda E\{\omega\} f'(l) \Phi(\delta) = 1 \tag{3}$$

$$\delta \equiv \frac{\ln(E\{y\}/(b - \pi(Y)))}{\sigma} + \sigma/2$$

where $\Phi(\cdot)$ is the cumulative distribution function of a standard normal, δ is the distance to default, and σ is the standard deviation of $\ln(\omega)$.

This first-order condition implies that, since $\Phi(\delta)$ is less than one, banks' loans l are lower than the optimal level l^*, which is implicitly defined by $\Lambda E\{\omega\} f'(l^*) = 1$. What distorts the bank's lending decision is the debt overhang, the anticipation that, in the event of default, the marginal benefit of lending will accrue to the bank's creditors, not to the equity holders. Consider the bank's marginal decision to lend one extra-unit of resources. This unit is expected to increase the revenue by the marginal expected product $\partial E\{y\}/\partial l$. However, this unit will also increase the expected debt repayments by the bank, since the marginal benefit of this lending will be reaped by the creditors in the case of default, and this is what discourages the bank's lending.

For intuition, it is helpful to interpret δ as the normalized distance between $E\{y\}$ and $b - \pi(Y)$, i.e. the distance to default; $\Phi(\delta)$ as the adjusted probability of full debt repayment, i.e., of $y + \pi(Y) - b \geq 0$; and $1 - \Phi(\delta)$ as the probability that the bank defaults on its liabilities. The default probability, $1 - \Phi(\delta)$, acts like a tax that discourages banks' new lending, and is the correct indicator for the size of the debt overhang distortion.

Bank loans have positive spillovers. The decision of other banks to increase aggregate lending, raises aggregate output Y, raises the value of the assets held by a bank, lowers its risk of default and debt overhang distortion, and raises the expected marginal return of loans, $E\{\omega\} f'(l) \Phi(\delta)$, for any given level of bank loans l.[8] Let

$$\Phi_Y \equiv \frac{\partial \ln(\Phi(\delta))}{\partial \ln(Y)} = \frac{\Phi'(\delta)}{\Phi(\delta)} \frac{1}{\sigma} \frac{Y}{b - \pi(Y)} \pi'(Y) \tag{4}$$

be the elasticity of the probability of debt repayment to aggregate output.

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[8]We disregard the effect of aggregate output Y on the discount factor Λ because it is present in all macroeconomic models and does not have any relevant policy implication.

This positive externality generates a contagion mechanism: When a bank's risk of default, $1 - \Phi(\delta)$, rises, the debt overhang distortion rises, and the bank contracts its loans l; the contraction of bank lending worsens aggregate economic conditions Y, decreases the value of other banks' financial assets $\pi(Y)$ and raises their risk of default.

This contagion mechanism can amplify small shocks and could explain economic booms and busts accompanied by corresponding booms and busts in asset prices and lending activity. More importantly, it has the potential to generate multiple equilibria and can give rise to a financial crisis. If there are pessimistic views of the financial sector, banks' risk of default and debt overhang distortion rises, leading to under-lending and self-fulfilling poor performance of the financial sector. This is similar to the mechanism studied by Lamont (1995), who shows that multiple equilibria can arise when firms' investments are distorted by debt overhang and have positive spillovers, i.e. the net present value of investing depends positively on other firms' investment. In our paper, banks play the role that firms play in Lamont's model, and banks' loans play the role of firms' investments, leading to the potential for multiple equilibria.

Equilibria

To characterize equilibria, substitute the expression for Λ into the first-order condition (3), and obtain:

$$\frac{\beta u'(e_2 + Y)}{u'(e_1 + m - l)} E\{\omega\} f'(l) \Phi(\delta) = 1 \tag{5}$$

$$\delta = \frac{\ln(Y/(b - \pi(Y)))}{\sigma} + \sigma/2$$

where $Y \equiv E\{\omega\} f(l)$. The solutions l to this functional equation are the candidate equilibria. Each candidate equilibrium is an equilibrium only if, given Λ and Y, l solves the bank's problem (2).

Notice that, if $\pi(Y)$ did not depend on Y, there would be a unique value of l that solves the banks' problem, so the equilibrium would be unique. However, the dependence of $\pi(Y)$ on Y, and the associated spillovers, raises the possibility

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of multiple equilibria. Multiple equilibria arise when the sensitivity of the banks' financial assets to aggregate economic activity, κ_Y, is high.

For each equilibrium, we can compute the asset values using the discount factor Λ. The banks' bond value is equal to $\Lambda E\{\min(y + \pi(Y), b)\}$, while the banks' equity value is equal to $d_1 + \Lambda E\{d_2\}$. The value of banks' assets is equal to the sum of the bond and equity value, i.e. $d_1 + \Lambda(Y + \pi(Y))$. Let the capital ratio be the ratio of the equity value to the asset value. The risk-free rate is equal to $1/\Lambda - 1$. Notice that, since there is no aggregate uncertainty, the expected rate of return of any asset is equal to the risk-free rate. The bond yield (which is not an expected rate of return), is equal to the ratio of the bond face value b, to the bond value, as defined above, minus one. The bond spread is the difference between the bond yield and the risk-free rate.

4 Financial fragility

In this section, we narrow down our focus on an economy where debt overhang on bank lending makes the economy financially fragile.

Parameter values

The parameter values, listed in Table 1, are set so that the economy has two equilibria, a normal equilibrium and a financial crisis equilibrium, and the normal equilibrium describes an economy in a normal state.

One period is one year. $E\{\omega\}$ is normalized to 1. The parameter values $\alpha = 0.3$, $\beta = 0.99$, and $\gamma = 1$ are standard. The volatility of the idiosyncratic productivity shock is $\sigma = 0.8$, which implies a quarterly volatility of 40%.[9] The default probability is set equal to 2.24%, to match the average default rate (U.S. All Corporates, 1984:I—2011:IV, Moody's).

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[9]As we will see, with this high value for the volatility, the probability distributions of the returns of an individual bank's bonds and assets has two modes. If we chose a lower, more standard, value, for instance a quarterly volatility of 20%, all the qualitative results would continue to hold, except that there would be only one mode in those probability distributions.

We set $c_1/l = 5$, to match, approximately, the 2013:Q4 ratio of Personal Consumption Expenditures to new loans—new loans are computed by dividing total loans by their average maturity, that is 3.23 years (Commercial banks, Federal Reserve Call Report). The consumption growth rate $c_2/c_1 - 1$ is 2.5%. Dividends are 4% of equity, which implies an equity-dividend ratio of 25. The capital ratio is 11%, to match, approximately, the 2013:Q4 ratio of equity to assets (Commercial banks, Federal Reserve Call Report).

We set $a_V = 0.0075$, so each bank holds claims to the assets of other banks for 0.75% of the value of the representative bank, to match, approximately the 2013:Q4 ratio of interbank loans to total assets (Commercial banks, Federal Reserve Statistical Release, H.8).

We set $\bar{Y}$ equal to the level of output Y in the normal equilibrium, and $a_Y = 3$, so that the value of assets that depend directly on aggregate output Y is equal to 3 times the new loans l. This approximately matches the 2013:Q4 ratio of risky assets to new loans— new loans are computed as described above, while risky assets are computed as the difference between total assets and the sum of Treasury and agency securities, new loans, interbank loans, and cash assets (Commercial banks, Federal Reserve Statistical Release, H.8).

The sensitivity $\tau = 2$ is set high enough so that the model has two equilibria. These parameter values imply that $\kappa_Y = 6.0529$. The next section is devoted to compare this economy to other economies with lower τ and κ_Y.

The other parameters are either determined by the above setting (b and $\bar{a}$), or do not affect the equilibrium—in particular, the distribution of goods in the first period between households and banks is irrelevant.

The normal equilibrium and the financial crisis equilibrium

The values of the key variables in the two equilibria are summarized in Table 2. Relative to the normal equilibrium, economic activity is dramatically lower in the financial crisis equilibrium. The default probability jumps from 2.25% to 71.47%, raising the debt overhang. Loans are 39.17% smaller, and output produced with

loans drops by 13.86%. The risk-free rate drops to a large negative value, while the bond spread jumps to 4.46 percentage points. As a result, the bond yield decreases, and the bond value increases. This latter result depends on parameter values—in general, the change in the bond yield and in the bond value can be positive or negative, depending on the opposite forces of the lower risk-free rate and of the higher bond spread. The banks' equity value plunges by 52.22%. The value of bank assets rises by 5.96%, although this result is also dependent on parameter values. The capital ratio drops from 11% to 4.96%.[10]

5   Systemic risk

In this section, we investigate how systemic risk can be detected and measured before a financial crisis may occur. First, we study what distinguishes *robust* economies, the ones where the equilibrium is unique, from *fragile* economies, the ones where a financial crisis can occur. Then, we study how to detect the emergence of systemic risk in a specific economy over time. Finally, we study how to measure changes in systemic risk in a fragile economy over time.

To tackle these issues, we add an assumption about the likelihood of a financial crisis in the fragile economy. We assume that, if the economy has multiple equilibria, then a sunspot variable is realized right before banks make their decisions. The sunspot variable leads the economy in the financial crisis equilibrium, with probability $q \in (0, 1)$, and in the normal equilibrium with probability $1 - q$. For

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[10]The first-period dividends d_1 increase during the crisis. This is the consequence of the limited set of options available to banks. The banks' initial funds m are constant, and banks can only lend them or distribute them as dividends, so a drop in l during the crisis necessarily entails a rise in d_1. This model prediction is not robust to modifications of the model where banks have additional options to raise or use funds. For instance, if banks could borrow short-term from households and if short-term borrowing dropped during a crisis, as it happens in reality, dividend distributions would drop as well. For this reason, it is better to interpret the rise of d_1 in the model more broadly as a rise in the cash outflow from banks to households, resulting from several factors including a drop of short-term borrowing. In the rest of the paper, we will disregard this model prediction about d_1.

illustrative purposes, we set q equal to 10%, so that on average there is a financial crisis every 10 years.

Detecting the existence of systemic risk

It is hard to find clear indicators of the existence of systemic risk. The most obvious warning signal would be a high value for the sensitivity of banks' financial assets to aggregate economic activity, or a high value of κ_Y in our model. However, the precise threshold that leads to multiple equilibria depends on the specifics of the economy, including the other parameters' values. Hence, a high value for this sensitivity does not necessarily signal the existence of systemic risk.

Considering Table 2, one is led to consider signals such as high default probability and leverage, low expected values of real activity, low equity values, low risk-free rates and high bond spreads. However, none of these signals is reliable, because all of these signals can be present in a robust economy.

To see this point, we compare our fragile economy with a robust economy with the same default probability and equity-asset ratio—In the latter economy, $\tau = 1$, $\bar{a}/Y = 3.4858$, and $b/Y = 6.7929$. As shown in Table 3, the expected values are very similar in the two economies, even though one is fragile and the other is robust. The only small differences are that, in the fragile economy, the risk-free rate (as well as the expected rate of return on a generic asset) tends to be slightly lower and the bond spread tends to be a little larger. In sum, this comparison shows that it is hard to detect the existence of systemic risk looking only at default probability and leverage, expected values and asset values, interest rates and spreads.

A clearer signal of financial fragility comes from the probability distributions of variables. These distributions can be obtained directly from the public's expectations or indirectly from the prices of derivative securities. In the fragile economy, differently from the robust economy, the support of the probability distributions for aggregate real variables, such as loans and output, and financial variables, such as future interest rates and asset values, includes two values, the ones listed in Ta-

ble 2. Standard deviations are non-zero in the fragile economy only. A measure of the probability of a financial crisis can be obtained from the probability of the worse mode. More generally, one would look for the presence of two modes and a larger standard deviation in the probability distributions.

The clearest signals of financial fragility come from the probability distributions of asset returns. We look at the returns of a risk-free bond promising a constant payoff at the end of the second period; portfolios of banks' assets, debt and equity; the individual assets, debt and equity of each bank. As mentioned earlier, asset values after the realization of the sunspot variable are computed using the discount factor Λ. Asset values before the realization of the sunspot variable are computed simply as a weighted average (using the probabilities of the sunspot variable as a weight) of the post-realization asset values. From these asset values, we can compute two sets of rates of return: the returns from before the realization of the sunspot variable to immediately after the realization—the *before-after-sunspot returns*; and the returns from before the realization of the sunspot variable to the end of the second period—the *total returns*. The rates of return from immediately after the realization of the sunspot variable to the end of the second period are not that interesting: the rates of return of the portfolios of banks' assets, bonds and equity are the same as the risk-free rate, since there is no residual aggregate uncertainty; the ones of the individual banks' assets, bonds and equity only reflect the realization of the idiosyncratic shock ω.

Table 4 shows the probability distributions of the total returns of the risk-free bond and of the portfolios. The probability distributions of both the equity portfolio and the bond portfolio include two values, differently from the robust economy. A measure of the probability of a financial crisis can be obtained from the probability of the worse return of the equity portfolio. The total return of the risk-free bond is, obviously, risk free.

Table 5 shows the probability distributions of the before-after-sunspot returns of the risk-free bond and of the portfolios. The probability distributions of the before-after-sunspot returns of individual banks' assets, bonds and equity are the

same as the ones of the corresponding portfolios. The probability distributions of the risk-free bond and of the equity portfolio include two values, differently from the robust economy. A measure of the probability of a financial crisis can be obtained from the probability of the worse return of the equity portfolio. The before-after-sunspot return of the risk-free bond is higher in a financial crisis. This is because the risk-free rate drops to a negative value in the financial crisis (see Table 2), and this boosts the price of the risk-free bond. This effect is there for the prices of other assets as well, but, for other assets, it is offset by the drop of their expected payoffs. Risk-free bonds, then, are excellent hedges against the risk of a financial crisis.

Figure 2 plots the probability distributions of the total returns of an individual bank's assets, bonds and equity. For bonds and assets, they tend to be bimodal as well. Equity returns, however, don't show any bi-modality because of the long-call option feature of equity (as opposed to the short-call option feature of bonds). The changes in the distribution of returns of individual equities are hardly visible because of the large idiosyncratic risk of equities. A measure of the probability of a financial crisis can be obtained from the ratio of the second mode to the sum of the two modes of the probability distribution for assets. This measure, 0.1104, is close to the true probability of a financial crisis, 10%, and is increasing in it.

Table 6 compares the mean, standard deviation and correlation coefficient of the total returns of individual banks' assets, bonds and equity. The volatility of returns of individual banks' bonds is much larger in the fragile economy, with smaller recovery rates, which explains why bond spreads are higher. Correlations between different banks' returns of assets, bonds and equity also increase, especially for bonds. The correlation coefficient in the robust economy is zero, since there is no aggregate uncertainty and the idiosyncratic risk is independent across banks. Correlation coefficients become positive in the fragile economy because of the possibility of a financial crisis that affects all returns. The correlation of bond returns is especially affected. The correlation between different asset classes (assets, bonds and equity) increases as well, as shown in Table 7.

To summarize, the following are some signs of fragility. The probability distribution of real variables and of returns of portfolios of equities and bonds becomes bi-modal, with a higher standard deviation. The distribution of returns of individual bonds becomes bi-modal, with a higher standard deviation. Correlations generally rise, especially across bonds of different banks.

Detecting the emergence of systemic risk

We next turn to detecting the emergence of systemic risk in a specific economy over time. Suppose that the economy is initially robust, but then an increase in τ (due to an increase in a_Y) makes it fragile, i.e., a financial crisis equilibrium emerges besides the normal equilibrium. The increase in τ leaves the normal equilibrium unchanged (the default probability and all expected values remain the same), and simply adds the possibility of a financial crisis. Before the transition, the economy has a unique normal equilibrium, the same as the one in Table 2; after the transition, it has the two equilibria in Table 2.

The emergence of systemic risk, the transition from a robust economy to a fragile economy has a sudden effect on expected values. Table 8 shows that the following changes in expected values would be associated with the emergence of a financial crisis equilibrium: a surge of the default probability, a drop of the expected values of loans, output, equity values (and capital ratios) a drop of the risk-free rate (and more generally of expected returns) and a surge of the bond spread. Bond values and bond yields are less informative because of the countervailing forces of the drop of the risk-free rate and the increase in the bond spread.

However, the above changes can be due to several other causes. For instance, a drop of productivity has similar effects (see Table 9).

Hence, it is, again, better to rely on probability distributions of variables and of returns. The distribution of aggregate variables and of portfolio returns, will tend to have two modes, and a higher standard deviation.[11] The same is true for

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[11]Most tables and figures of comparison are omitted because they are similar to the ones in the previous section.

individual banks' bond returns; returns of individual banks' equities and bonds will tend to have higher correlations among each other (see Table 10). A second mode and a long tail of negative returns appear in the probability distribution of each bank's asset and bond total returns (see Figure 3).

Measuring an increase in systemic risk

We finally study how to measure an increase in systemic risk in a fragile economy over time. Suppose that the economy continues to have the same two equilibria, but the probability q of the financial crisis equilibrium rises.

The changes that would signal the emergence of systemic risk would also signal a rise of systemic risk. For instance, a surge of the default probability, a drop of the expected values of loans, output, equity values (and capital ratios), a drop of the risk-free rate (and more generally of expected returns) and a surge of the bond spread[12] (see Figure 4). Again, it is better to rely on probability distributions of portfolios and individual banks' securities. Two modes tend to appear, and standard deviations and correlations tend to increase. Notice, however, that this is only true in the region where the probability of a financial crisis is small. (see Figures 5, 6 and 7).

If the probability q is small, a measure of the probability of the financial crisis can be obtained from the probability of the second mode in the case of portfolio returns, or the ratio of the second mode to the sum of the two modes of the probability density function of returns of individual banks' assets (see Figure 8).

6 Policy

In this section, we discuss the policies that the model suggests should be implemented to prevent, eliminate or reduce systemic risk; and to reduce the effects of a crisis once it takes place.

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[12]The expected values can be easily computed by averaging the values of Table 2.

Macroprudential regulation

The potential for multiple equilibria arises from the positive spillovers of bank loans generated by the dependence of the expected marginal return of loans on aggregate lending, which in turn follows from the dependence of the bank asset value to aggregate output and more generally from the bank exposure to the economic and financial cycle. Because it is an externality, banks do not take it into account when they choose their balance sheet structure, and this justifies the use of prudential tools to limit this dependence and stabilize the financial system. This objective is distinct from the traditional objectives of micro-prudential regulation, that are the mitigation of the moral hazard associated with government-insured deposits, the protection of government deposit-insurance funds, and the safety of the individual financial institution.

The main target of policy should be limiting the dependence of the expected marginal return of loans, $E\{\omega\}f'(l)\Phi(\delta)$, on aggregate output Y, for given loan amount l. This amounts to limiting the elasticity Φ_Y of the repayment probability to aggregate output. More generally, the target is limiting the common default risk exposure of banks to the economic and financial cycle. This target is distinct from limiting the individual risk of default of an individual financial institution, or the overall risk of default of the financial system—in fact, limiting the latter does not necessarily eliminate the financial fragility: the risk of default may be tiny even in a financially fragile economy, in the case that the probability of a financial crisis is small.

A first policy tool is restricting banks from investing in risky assets sensitive to the business cycle or to the financial sector. As is clear from equation (1), to limit the sensitivity, it is especially important to restrict interbank lending and investment, and more generally bank interconnectedness. The rationale behind this restriction is new. Legislation that restricts banks from trading and investing mainly aims at preventing banks from using deposits for speculative activities.[13]

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[13]In the U.S., the Glass-Steagall legislation (Banking Acts of 1933 and 1935) separated commercial banks from investment banks and securities firms; prohibited the former ones from

There may be, also, concerns about potential conflicts of interest. This paper, however, suggests that restricting banks' speculative investment in securities helps reduce the systemic risk associated with the correlation between bank assets and economic activity.

For asset investment that cannot be restricted, policy should impose capital requirements aimed at limiting the bank default risk exposure to the economic and financial cycle. This capital requirement, aimed at eliminating the financial fragility, is in addition to any capital requirement aimed at ensuring the safety of the individual financial institutions. As noted by Hanson, Kashyap and Stein (2013). the capital should be in the form of common equity, assuming that managers act in the interest of the equity holders, not in the form of preferred equity or of other senior types of capital, which still create a debt overhang distortion on lending. The perfect tool is a stress test that evaluates capital strength and bank risk in the event of a financial crisis. Alternatively, a capital ratio could be used, with risk weights set to limit the elasticity Φ_Y of the repayment probability to aggregate output. From equation (4), evaluated in equilibrium, it follows that

$$\Phi_Y = \frac{\Phi'(\delta)}{\Phi(\delta)} \frac{e^{\delta\sigma - \sigma^2/2}}{\sigma} \pi'(Y) \qquad (6)$$

For standard parameter values, for instance for $\sigma \leq 1$ and for $\delta \geq 1$, the right hand side is a decreasing function of the distance to default δ. Hence, in order to limit Φ_Y, the policy authority should require a larger distance to default δ whenever the sensitivity $\pi'(Y)$ of assets to aggregate output is higher. That is, it should require a higher capital ratio, which entails a larger distance to default δ and a lower risk of default $1 - \Phi(\delta)$, to banks with assets that are more sensitive to the cycle—banks with high-beta assets. Risk weights, then, should be set higher for higher-beta assets that are more sensitive to the economic and financial cycle, and could be set negative for assets that co-vary negatively with the cycle.

investing in non-investment grade securities for their own portfolio, and from dealing, underwriting and distributing non-government securities; and prohibited the latter ones from taking deposits. the Volcker rule (2010 Dodd-Frank Act) restricts banks and affiliates from proprietary trading, while allowing hedging as well as trading, market-making and dealing as services for customers.

Crisis policies

Suppose the economy is fragile and the sunspot variable indicates that there will be a crisis. Economic forecasts are signaling a deep, long contraction, asset values have crashed, bank balance sheets have weakened. However, suppose that we are at the very beginning of the crisis, bank lending is contracting but there is still room for policy to act to eliminate the crisis equilibrium. This can be done with various tools that either raise the expected return on bank loans, or strengthen the bank balance sheets, or otherwise reduce the debt overhang.

The first set of policy tools consists of changes in fiscal policy, such as lower taxes or higher government spending, designed to raise the expected return on bank loans, stimulate the economy, and raise the value of financial assets. For instance, suppose that government spending, g, financed with lump-sum taxes, raises the productivity of bank loans. For instance, suppose that the production function is $y \equiv f(l,g) \equiv Al^\alpha g^\eta$, $\eta \in (0,1)$, so that $f_{l,g}(l,g) > 0$, and the first-period feasibility constraint is $c_1 = e_1 + m - l - g$. In this case, raising government spending g can eliminate the financial crisis equilibrium.

Policy can strengthen bank balance sheets by lowering the real value of bank liabilities. If debt is set in nominal terms, unanticipated inflation lowers the real value of debt, strengthen bank balance sheets, and lowers the debt overhang distortion. Occhino and Pescatori (2014) and Gomes, Jermann and Schmid (2013) study the optimal setting of monetary policy in a debt overhang economy. Alternatively, monetary policy can strengthen bank balance sheets by raising the value of bank assets. Monetary policy may be able to raise the value of bank assets by lowering the interest rate. Or by defending the exchange rate in the case of a banking crisis associated with a currency crisis. If bank assets are denominated in the local currency, while bank liabilities are denominated in a foreign currency, and if the local currency depreciates as domestic economic conditions deteriorate, then the economy is vulnerable to a debt-overhang financial crisis where domestic economic activity declines, the local currency depreciates, the banks' balance sheets weaken, and the debt overhang distortion rises and discourages lending. In

this case, the central bank may be able to eliminate the crisis by intervening to defend the exchange rate, which would strengthen the banks' balance sheets, reduce the debt overhang distortion, and stimulate bank lending and economic activity. Similarly, in the case of a banking crisis associated with a sovereign debt crisis, where banks hold sovereign debt and the government's ability to repay depends on economic conditions, the central bank may be able to eliminate the crisis by purchasing the sovereign debt.

A final set of tools consist in encouraging or forcing a restructuring of bank capital and ownership. For instance, under the Capital Purchase Program within the 2008 Troubled Asset Relief Program (TARP), the U.S. Treasury provided approximately $205 billion of capital to 707 financial institutions, on a voluntary basis. The goal of the program was to avert a financial system collapse and a bank lending freeze. One problem with this program was that the government received preferred stock and debt securities, rather than common equity, and this may have amplified, rather than reduced, the debt overhang distortion on the lending decision, as pointed out by Wilson and Wu (2012) and Wilson (2012). When bank participation is voluntary, the government capital needs to be subsidized relative to the financial crisis equilibrium, but not necessarily relative to the normal equilibrium. Voluntary participation, however, may raise issues of free riding—if enough banks participate and the financial crisis is avoided. Alternative tools the government could force a government capital injection, or require a private recapitalization. A more drastic measure would be wiping out the debt and transferring the ownership to the creditors. These tools have to be implemented simultaneously for a large part of the financial system, so they may be especially expensive.

Contingent policies and guarantees

The same policies that are successful in eliminating the crisis equilibrium, may eliminate the financial fragility if credibly announced as contingent policies. For instance, in the case of banking crises associated with currency crises or sovereign

debt, the credible commitment to defend the exchange rate or to purchase government debt may be sufficient to eliminate the financial crisis equilibrium. Indeed, this may explain what occurred during the recent Eurozone crisis. In the early part of 2012, credit spreads for both the government and the banks of the European periphery countries, of Italy and Spain in particular, rose sharply, with relatively little change in the economic fundamentals. In response, the ECB President Draghi declared in July that the ECB was ready to do "whatever it takes" to save the single currency; right after that the ECB introduced the Outright Monetary Transactions program with a commitment to purchase sovereign bonds for potentially unlimited amounts. This credible guarantee eliminated the crisis equilibrium almost immediately—almost immediately, credit spreads began to decline steadily.

Another example is the use of contingent capital instruments by banks, for instance, contingent convertible bonds, i.e., debt instruments that automatically convert to equity once the risk of default crosses a threshold. The instrument should be contingent on aggregate conditions, not on the individual banks' conditions. Other contingent assets that may work are debt instruments that are wiped out in the event of a financial crisis, or assets that pay off in the event of a financial crisis, as suggested by Hanson, Kashyap and Stein (2013).

7   Conclusion

In this paper, we have studied how a self-fulfilling expectations financial crisis can arise when banks hold financial assets that are sensitive to aggregate conditions, and existing debt distorts bank lending. Some signals of the existence of systemic risk include: a rise in the volatility and the presence of two modes in the probability distribution functions of the returns of bank-issued bonds and of portfolios of bank-issued bonds and equities; and a surge in the correlation between bank-issued bond returns. Macroprudential policy should limit the sensitivity of the bank risk of default to the economic and financial cycle by restricting bank investment and by enforcing capital requirements also based on stress tests with financial crisis

scenarios. In the event of a crisis, policy should reduce the sensitivity of bank assets to the cycle using commitments and guarantees, should stimulate the economy, should strengthen bank balance sheets, and should restructure bank capital and ownership.

The debt-overhang mechanism that we have described can explain a variety of economic and banking crises where a rise of the risk of default in the banking sector is accompanied by the plunge of assets sensitive to economic activity, such as financial securities, sovereign debt and the exchange rate. The same mechanism can also amplify small real and financial shocks, and can explain prolonged periods of weakness (or strength) of financial asset values, bank balance sheets, bank lending and economic activity. We hope that empirical research will find this mechanism useful for the study of historical episodes of financial, banking and economic weakness—the debt-overhang explanation seems especially promising, relative to the traditional liquidity-based ones, for episodes of persistent banking stress of the solvency type, for instance for the later stages of the U.S. Great Depression, for Japan's Lost Decade, and for the recent crisis of the European periphery countries.

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Parameter values

$E\{\omega\}$	1.0000
α	0.3000
β	0.9900
γ	1.0000
σ	0.8000
Consumption-loans ratio	5.0000
Consumption growth rate	0.0250
$\bar{a}/Y$	3.9978
a_V	0.0075
a_Y	3.0000
τ	2.0000
$\bar{\kappa}/Y$	1.0053
κ_Y	6.0529
b/Y	7.2043
Default probability	0.0225
Dividends-equity ratio	0.0400
Equity-asset ratio	0.1100

Table 1: Values of parameters and of selected variables in the normal equilibrium.

Equilibrium values in the fragile economy

	Normal equilibrium	Crisis equilibrium	Percent difference
Default probability	0.0225	0.7147	
Loans	0.1667	0.1014	-39.1730
Output	0.5766	0.4968	-13.8552
Risk-free rate	0.0354	-0.1297	
Bond spread	0.0001	0.0448	
Bond yield	0.0355	-0.0849	
Asset value	4.5079	4.7768	5.9640
Bond value	4.0120	4.5399	13.1557
Equity value	0.4959	0.2369	-52.2234
Equity-asset ratio	0.1100	0.0496	

Table 2: Equilibrium values in the normal equilibrium and in the financial crisis equilibrium.

Expected values in the robust and fragile economies

	Robust economy	Fragile economy
Default probability	0.0917	0.0917
Loans	0.1667	0.1601
Output	0.5849	0.5687
Risk-free rate	0.0354	0.0188
Bond spread	0.0010	0.0046
Bond yield	0.0363	0.0234
Asset value	4.2786	4.5348
Bond value	3.8338	4.0648
Equity value	0.4448	0.4700
Equity-asset ratio	0.1040	0.1040

Table 3: Expected values in the robust and fragile economies. In the robust economy $\tau = 1$, while in the fragile economy $\tau = 2$. The parameters $\bar{a}$ and b are changed so that the default probability and the equity-asset ratio are the same in the two economies.

Total returns of portfolios

	Normal equilibrium	Crisis equilibrium	Mean	Std. Dev.
Risk-free bond	0.0161	0.0161	0.0161	0.0000
Asset portfolio	0.0292	-0.0832	0.0180	0.0337
Bond portfolio	0.0219	-0.0280	0.0169	0.0150
Equity portfolio	0.0924	-0.5613	0.0270	0.1961

Table 4: Total returns of the risk-free bond and of portfolios of bank securities in the fragile economy.

Before-after-sunspot returns of portfolios

	Normal equilibrium	Crisis equilibrium	Mean	Std. Dev.
Risk-free bond	-0.0186	0.1675	-0.0000	0.0558
Asset portfolio	-0.0059	0.0534	0.0000	0.0178
Bond portfolio	-0.0130	0.1169	-0.0000	0.0390
Equity portfolio	0.0551	-0.4959	0.0000	0.1653

Table 5: Before-after-sunspot returns of the risk-free bond and of portfolios of bank securities in the fragile economy.

Total returns of bank securities

	Robust economy			Fragile economy		
	Mean	Std. Dev.	Corr.	Mean	Std. Dev.	Corr.
Assets	0.0354	0.1294	0.0000	0.0180	0.1235	0.0746
Bonds	0.0354	0.0038	0.0000	0.0169	0.0201	0.5545
Equity	0.0354	1.2378	0.0000	0.0270	1.1462	0.0293

Table 6: Moments of total returns of individual bank securities in the robust and fragile economies. In the robust economy $\tau = 1$, while in the fragile economy $\tau = 2$. The parameters $\bar{a}$ and b are changed so that the default probability and the equity-asset ratio are the same in the two economies.

Correlation of total returns of bank securities in the fragile economy

	Assets	Bonds	Equity
Assets	0.0746	0.2034	0.0467
Bonds	0.2034	0.5545	0.1274
Equity	0.0467	0.1274	0.0293

Table 7: Correlation of total returns of bank securities in the fragile economy.

Expected values after the emergence of systemic risk

	Robust economy	Fragile economy	Percent difference
Default probability	0.0225	0.0917	
Loans	0.1667	0.1601	-3.9173
Output	0.5766	0.5687	-1.3855
Risk-free rate	0.0354	0.0188	
Bond spread	0.0001	0.0046	
Bond yield	0.0355	0.0234	
Asset value	4.5079	4.5348	0.5964
Bond value	4.0120	4.0648	1.3156
Equity value	0.4959	0.4700	-5.2227
Equity-Asset ratio	0.1100	0.1040	

Table 8: Expected values in the robust and fragile economies. In the robust economy $\tau = 1$, while in the fragile economy $\tau = 2$. The other parameters are the same.

Expected values after a productivity shock

	Robust economy	Productivity shock	Percent or difference
Default probability	0.0225	0.0431	
Loans	0.1667	0.1657	-0.6072
Output	0.5766	0.5698	-1.1807
Risk-free rate	0.0354	0.0259	
Bond spread	0.0001	0.0003	
Bond yield	0.0355	0.0261	
Asset value	4.5079	4.5237	0.3509
Bond value	4.0120	4.0485	0.9091
Equity value	0.4959	0.4752	-4.1651
Equity-Asset ratio	0.1100	0.1050	

Table 9: The effect of a contractionary productivity shock in a robust economy. In both economies, $\tau = 1$. In the second economy, aggregate productivity $E\{\omega\}$ is lower by 1%. The other parameters are the same.

Total returns of bank securities after the emergence of systemic risk

	Robust economy			Fragile economy		
	Mean	Std. Dev.	Corr.	Mean	Std. Dev.	Corr.
Assets	0.0354	0.1211	0.0000	0.0180	0.1235	0.0746
Bonds	0.0354	0.0009	0.0000	0.0169	0.0201	0.5545
Equity	0.0354	1.1002	0.0000	0.0270	1.1462	0.0293

Table 10: Moments of total returns of individual bank securities in the robust and fragile economies. In the robust economy $\tau = 1$, while in the fragile economy $\tau = 2$. The other parameters are the same.

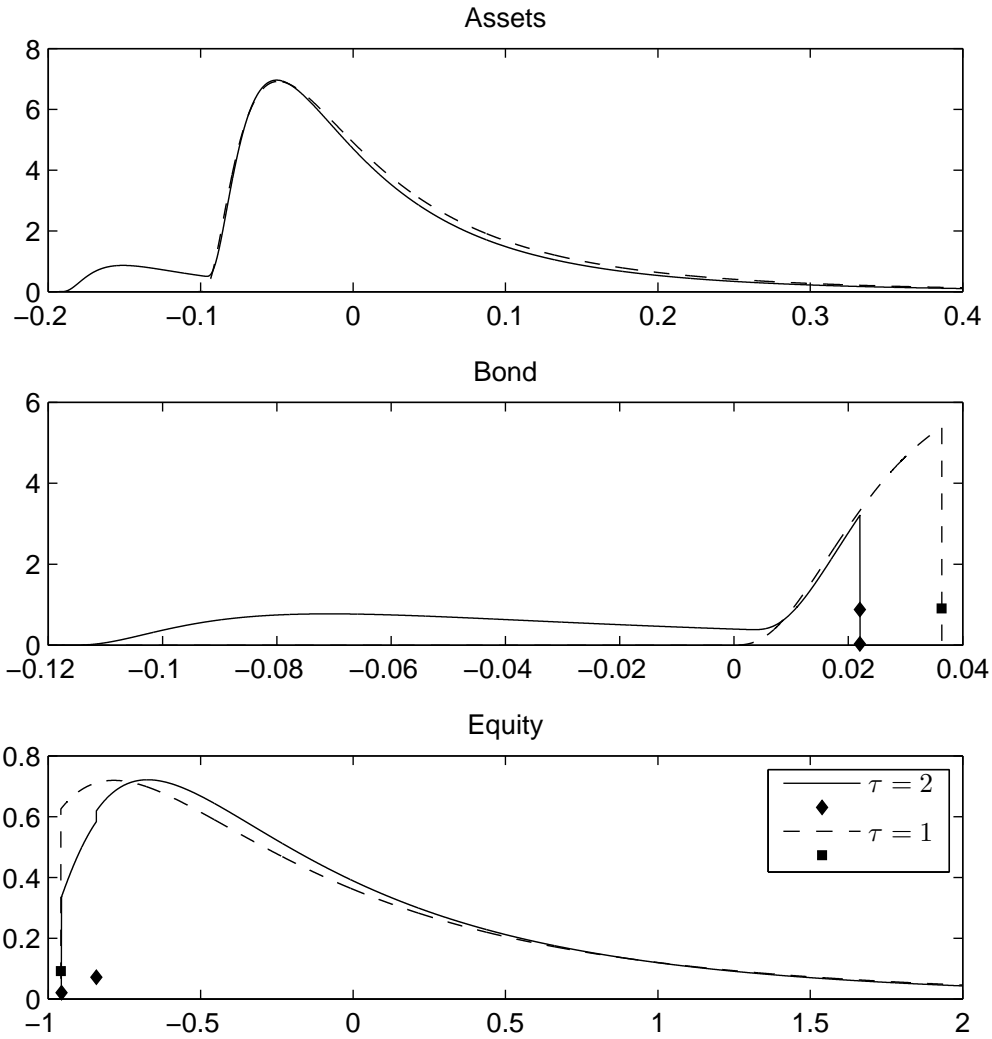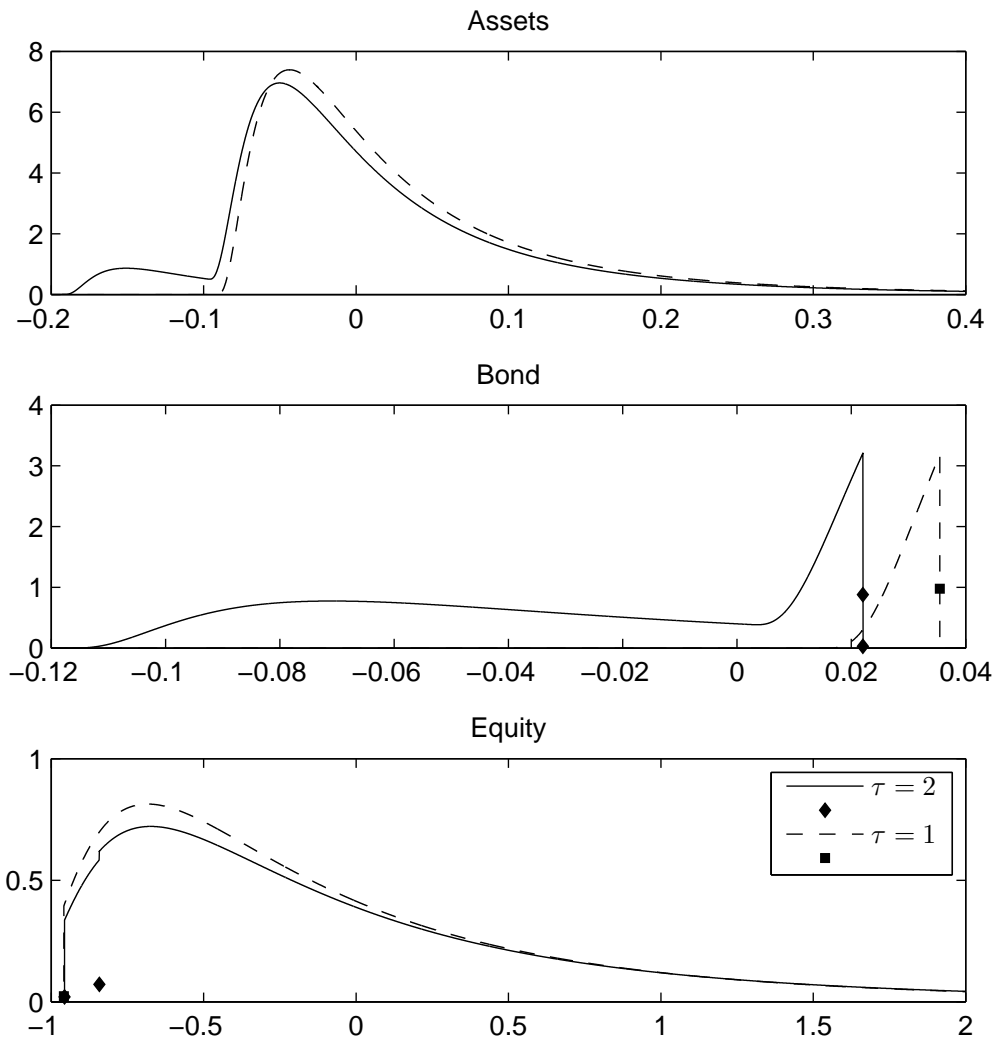# Probability distribution function of total returns of bank securities

Figure 2: Probability distribution function of total returns of bank securities. The solid lines and the diamond signs refer to a fragile economy where $\tau = 2$, the dashed lines and the square signs refer to a robust economy where $\tau = 1$. The parameters $\bar{a}$ and b are changed so that the default probability and the equity-asset ratio are the same in the two economies.

Probability distribution function of total returns of bank securities

Figure 3: Probability distribution function of total returns of bank securities. The solid lines and the diamond signs refer to a fragile economy where $\tau = 2$, the dashed lines and the square signs refer to a robust economy where $\tau = 1$. The other parameters are the same.
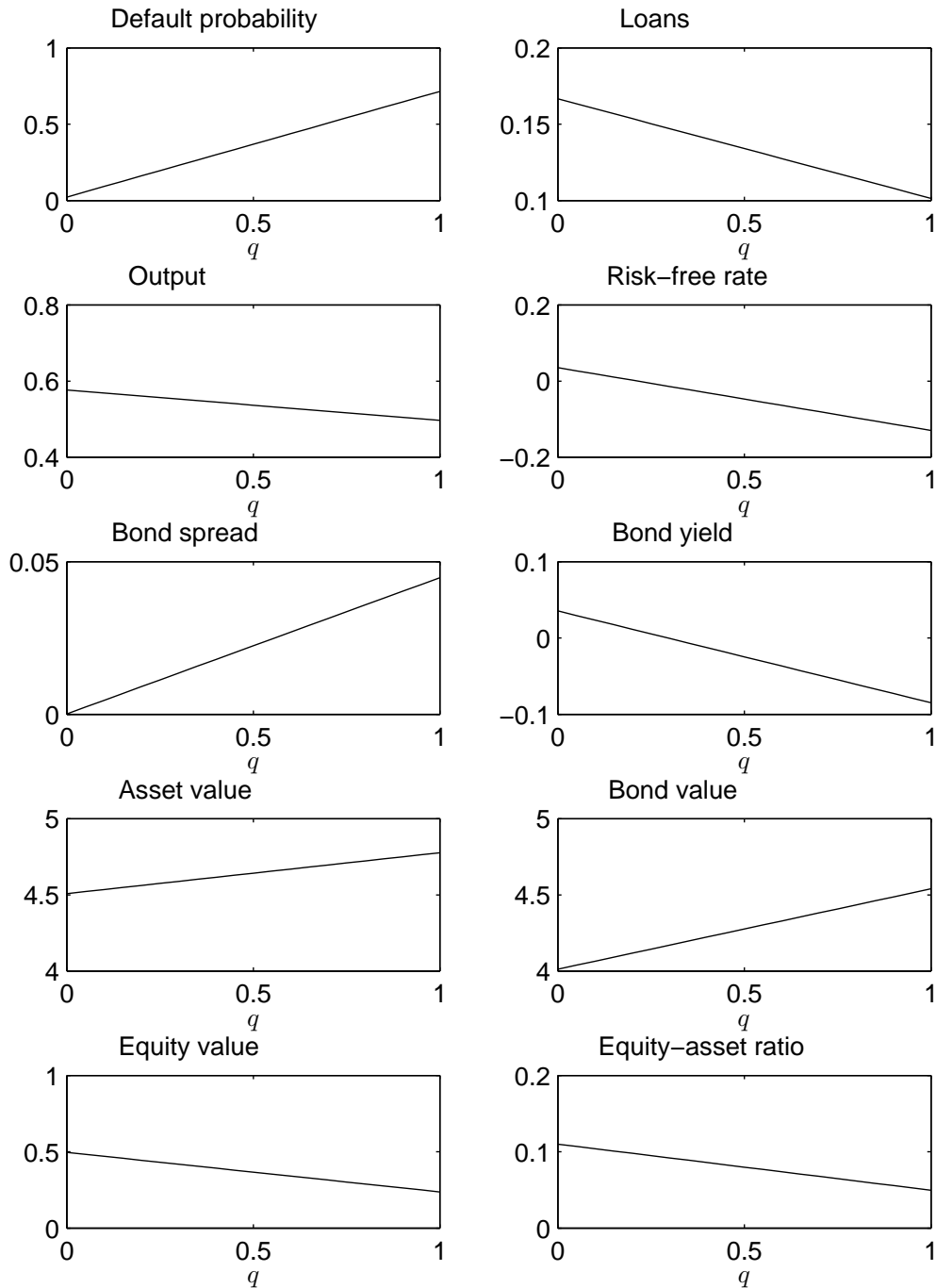
Expected values

Figure 4: Expected values as functions of the probability q of a financial crisis.
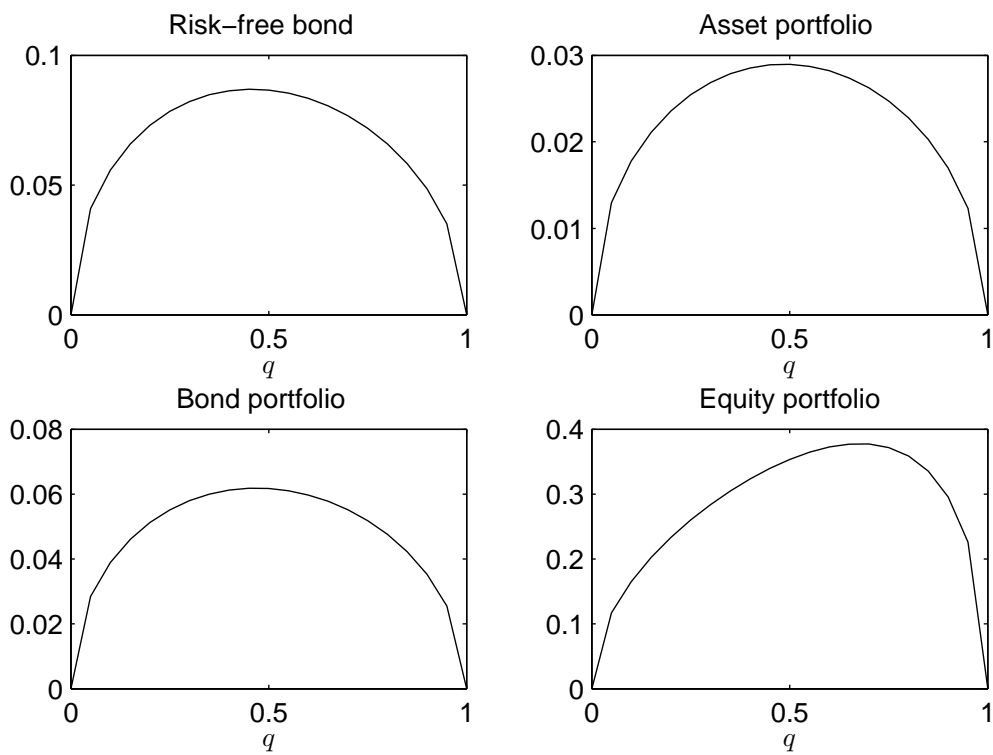
Standard deviations of before-after-sunspot returns

Figure 5: Standard deviations of before-after-sunspot returns as functions of the probability q of a financial crisis.

Standard deviations of total returns
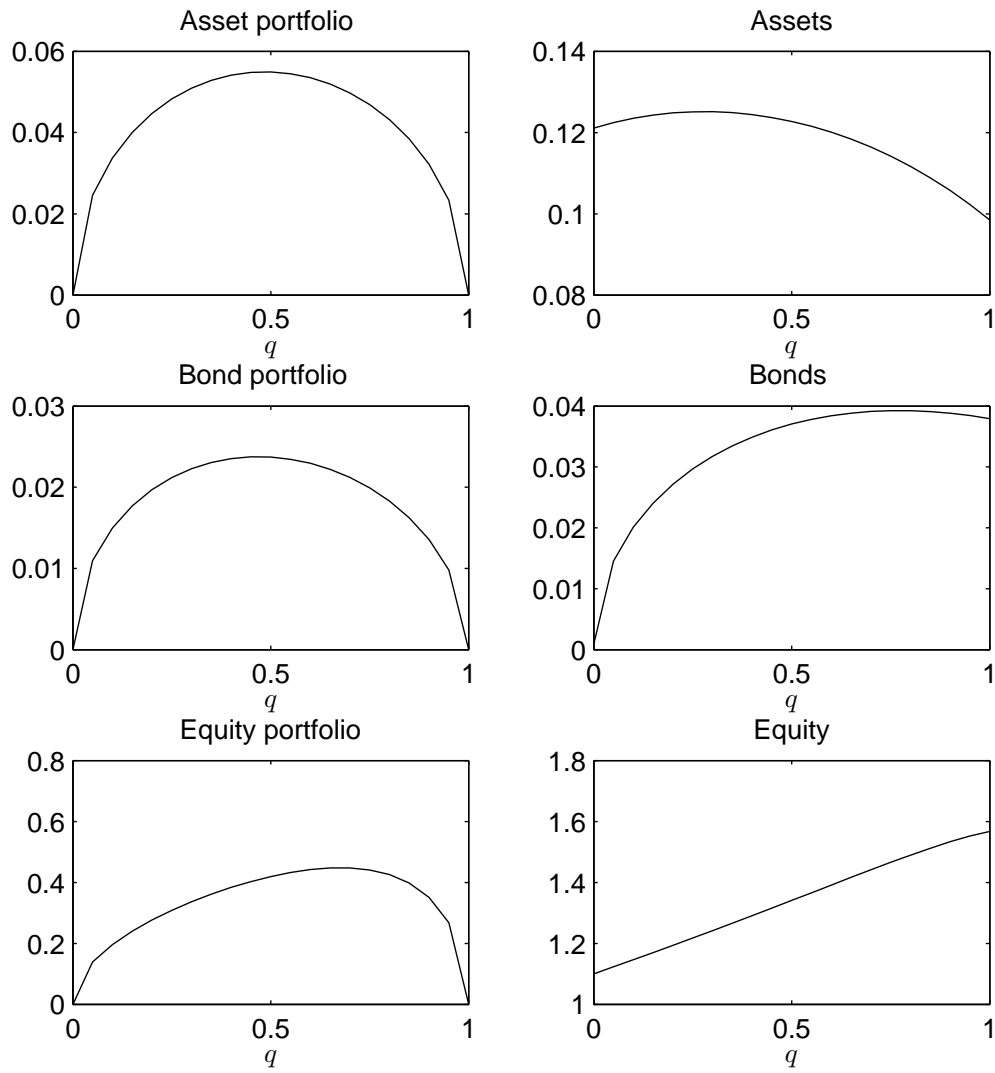

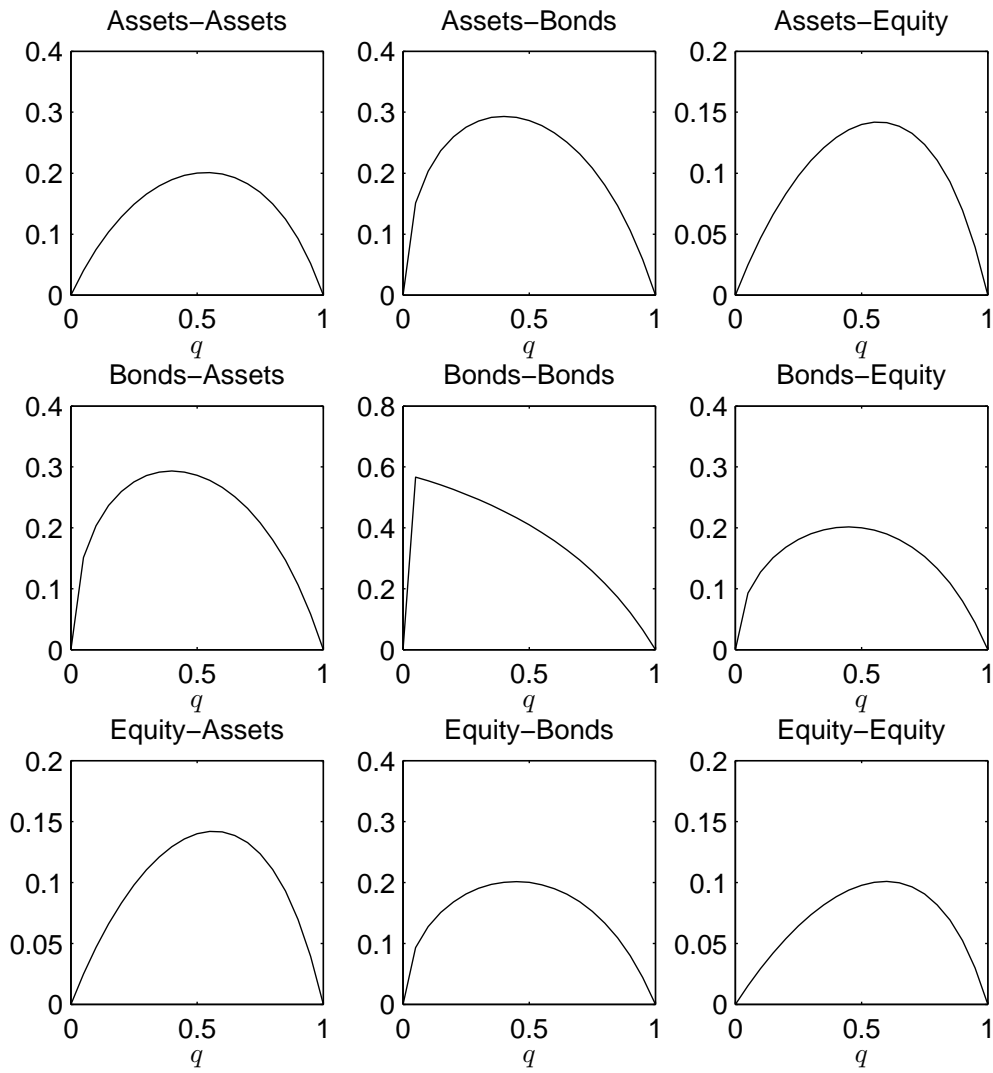Figure 6: Standard deviations of total returns as functions of the probability q of a financial crisis.

Figure 7: Correlations of total returns as functions of the probability q of a financial crisis.

Probability distribution function of total returns of bank securities
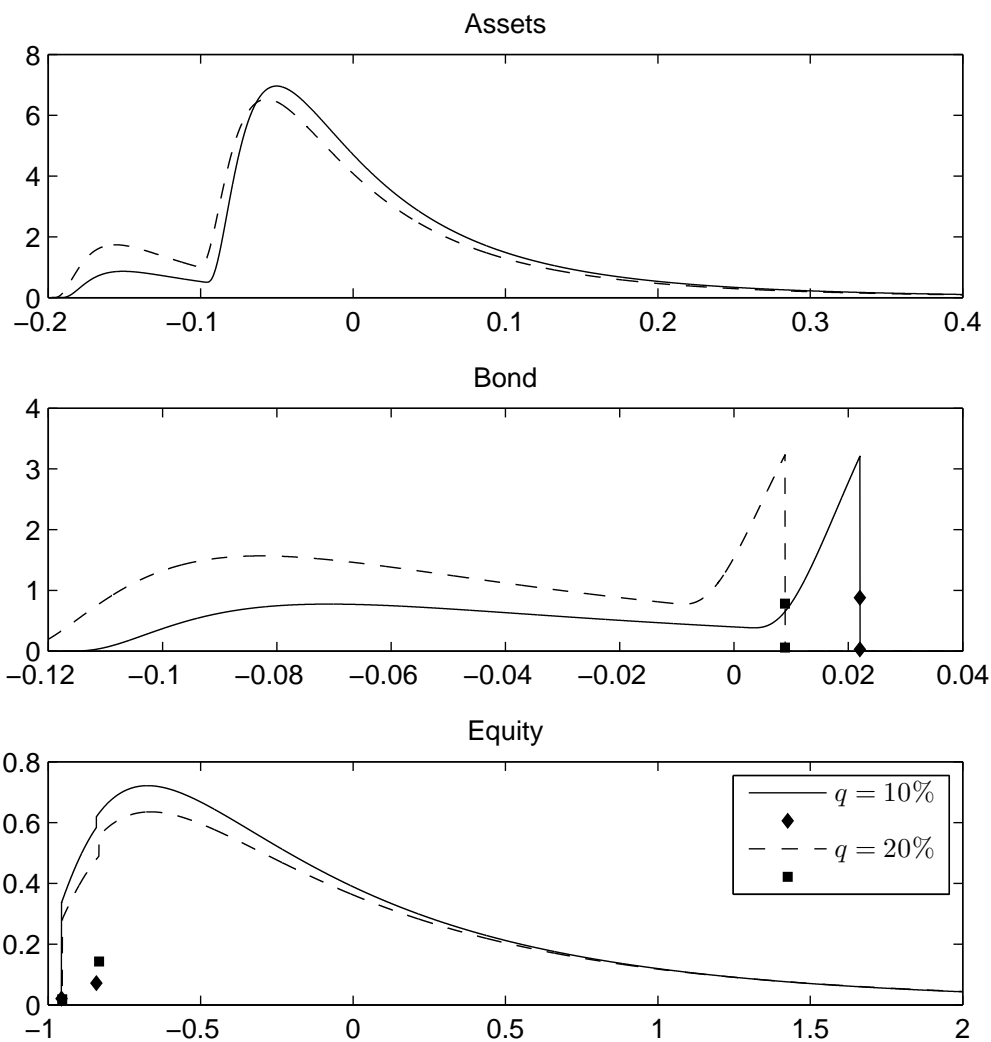

Figure 8: Probability distribution function of total returns of bank securities. The solid lines and the diamond signs refer to a fragile economy where the probability of a financial crisis is equal to $q = 10\%$, the dashed lines and the square signs refer to a fragile economy where the probability of a financial crisis is equal to $q = 20\%$. The other parameters are the same.