Balance-Sheet Shocks and Recapitalizations*

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Abstract

We develop a dynamic stochastic general equilibrium model with financial frictions on both financial intermediaries and goods-producing firms. In this context, due to high leverage of financial intermediaries, balance sheet disruptions in the financial sector are particularly detrimental for aggregate output. We show that the welfare gains from recapitalizing the financial sector in response to large but rare net worth losses are as large as those from eliminating business cycle fluctuations. We also find that these gains are increasing in the size of the net worth loss, are larger when recapitalization funds are raised from the household rather than the real sector, and may increase after a reduction in financial intermediaries idiosyncratic risk that raises leverage.

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1 Introduction

The Great Recession was characterized by a large collapse in asset values and a severe deterioration of financial intermediaries' balance sheets. This was associated with the freezing of credit markets and a dramatic contraction in output, which put pressure on governments and central banks to forcefully step in the economy. Traditional monetary and fiscal policies were complemented with more unconventional interventions, including the public recapitalization of banks. Inspired by these events, we develop a dynamic stochastic general equilibrium model to quantitatively assess the impact of rare but large shocks to the net worth of financial intermediaries and explore the merit of recapitalization policies.

The model is composed of three sectors, representing households, financial intermediaries, and firms in the non-financial corporate sector that we will refer to as the real sector. The household sector is made of a continuum of risk-averse workers which offer their labor endowment to real firms and deposit their savings with financial intermediaries. The financial sector includes a continuum of financial intermediaries subject to idiosyncratic shocks that raise deposits from households and lend to real firms. Finally, firms in the real sector borrow from financial intermediaries, hire workers and earn a rate of return subject to idiosyncratic shocks. All three sectors face the risk of exogenous net worth losses and both financial and real firms pay dividends to households at an exogenous rate.

The key feature of the model is presence of financial frictions not only on real firms, as already analyzed in the literature, but also on financial intermediaries. In the absence of financial frictions, the distribution of net worth across sectors is inconsequential for aggregate dynamics since capital freely flows to its most productive use through borrowing and lending. Financial frictions – that we model with a costly state verification problem *à la* Robert M. Townsend (1979) – prevent this efficient market-based reallocation of capital by generating spreads between the lending and borrowing rates. This implies that a given net worth loss in the economy has different economic implications depending on which sector it impacts.

Calibrating the model to U.S. data, we analyze the responses to a negative shock to the net worth of each of the three sectors. The model generates rich implications for the dynamics of both financial (leverage, spreads, and credit flows) and real variables (GDP, wages and profitability).

By considering financial frictions on financial intermediaries, our model reveals the particularly disruptive consequences of a shock to the financial sector. A given net worth loss involves indeed a much larger GDP contraction if it falls on the balance sheets of financial intermediaries rather than on households or real firms. This is essentially due to the high leverage of financial intermediaries that severely impairs their ability to withstand large shocks.

The fact that output losses depend on which sector is directly affected by the net worth shock provides the rationale for recapitalization policies that aim to shift losses to the sectors that can better absorb them. These transfers can in principle be implemented in many different ways, for example by easing monetary policies to reduce borrowing costs, by altering fiscal policies, by purchasing assets to support their values, or more directly through equity injections financed with tax-payer money. In this paper, we do not narrowly focus on any particular form of implementation, but consider more generally the welfare gains from exogenously redistributing wealth in response to shocks. Comparing the merit of different implementation procedures becomes an interesting topic of research only after establishing that the potential gains from recapitalization are reasonably large.

We assess the benefits of recapitalization policies in response to infrequent but large shocks that when affecting the financial sector trigger a GDP contraction similar to the U.S. 2008 recession. We find that the gains from recapitalizing the financial sector with funds from the household sector are equivalent to a permanent increase in consumption by 0.15%. To put this number in context, these are the gains that a standard RBC model without financial friction would predict from the elimination of business cycle fluctuations. Therefore, designing and implementing recapitalization policies in case of rare but large shocks to the financial sector could be equally important as the design of countercyclical policies aiming at smoothing business cycle fluctuations.

By including financial frictions on both the financial and the real sector, the model also allows us to consider the merit of recapitalizing the financial sector with funds from the real sector. At a first glance, this may seem inappropriate since the ultimate purpose of policy intervention is to support the level of investment in the real sector. However, since financial intermediaries are more leveraged than real firms, we find that financing the recapitalization with resources from the real sector is still welfare enhancing.

We also use the model to study how the welfare gains from recapitalization policies vary with the level of idiosyncratic risk.[1] This is an interesting issue in the context of the paper since under costly state verification the level of idiosyncratic volatility controls the importance of financial frictions which provide the rationale for recapitalizations. The model would indeed boil down to a standard frictionless world if idiosyncratic volatility were set to zero. A reduction in volatility can be beneficial for the economy since it reduces financial frictions. However, the model reveals that lower uncertainty also leads to a gradual increase in the leverage of financial intermediaries, which can make the economy less resilient to financial sector shocks and increase the welfare gains from recapitalization policies.

The modeling of financial frictions adopted in the paper is borrowed from Charles T. Carlstrom and Timothy S. Fuerst (1997) and Ben Bernanke, Mark Gertler and Simon Gilchrist (1999) who incorporated Townsend (1979) 's costly state verification framework in a dynamic macro model. The purpose of this early literature on financial frictions, also including Nobuhiro Kiyotaki and John Moore (1997), was to study the role of agency problems on good-producing firms in amplifying the responses to productivity shocks. Differently from our work, these papers did not feature a financial sector. The Great Recession demonstrated that a credit tightening may not only result from deterioration in the balance sheets of ultimate borrowers, but also from problems affecting the financial sector itself. Recent papers have thus incorporated a role for the lender either implicitly by shocking the tightness of credit constraints (Gilchrist, Sim and Zakrajšek (2010), Vincenzo Quadrini and Urban Jermann (2011), and Vasco Cúrdia and Michael Woodford (2009)), or by imposing financial frictions only on financial intermediaries (Mark Gertler and Nobuhiro Kiyotaki (2009)).

The main innovation in our paper is to consider financial frictions on both financial intermediaries and good-producing firms. Apart from improving the realism of the model, our setup allows us to compare the responses to shocks in the financial and real sector and assess the impact of wealth transfers between these two sectors. A double layer of financial frictions was first introduced by Bengt Holmstrom and Jean Tirole (1997) but in a static setting and with an exogenous lending rate by households. The models by Nan-Kuang Chen (2001) and Césaire A. Meh and Kevin Moran (2010) also feature financial frictions on both banks and firms, but use an agency problem based on

[1] Recent papers that give a prominent role to uncertainty shocks include Christina Arellano, Yan Bai and Patrick Kehoe (2011), Nicholas Bloom, Max Floetotto and Nir Jaimovich (2011), Lawrence Christiano, Roberto Motto and Massimo Rostagno (2009), and Simon Gilchrist, Jae W. Sim and Egon Zakrajšek (2010).

limited enforcement rather than on costly state verification. The advantage of the latter approach adopted in our paper is that it allows for the analysis of time-varying borrowing spreads and for the possibility of recapitalizing the financial sector with funds from the real sector which has instead no impact on output in the just cited papers. Naohisa Hirakata, Nao Sudo and Kozo Ueda (2011) also present a model with a costly state verification problem on both banks and real firms. Our work differs from theirs in two important ways: First, they assume a monopolistic bank, while we consider a competitive banking sector. Second, they solve the model with standard log-linear approximation methods, while we use global methods because the shocks associated with a systemic banking crisis are large enough that the system moves significantly away from the steady state. Finally, our paper shares with Mark Gertler and Peter Karadi (2010) and Marco Del Negro, Gauti Eggertsson, Nubuhiro Kiyotaki and Andrea Ferrero (2011) the purpose of analyzing unconventional policies in response to financial crises, but our focus is on recapitalizations instead of credit policies and liquidity support. Robert Kollmann, Werner Roeger and Jan in't Veld (2012) also study the merit of bank aid policies considering the impact on GDP, while we examine the implications for welfare.

This paper is organized as follows. The next section introduces the model which we calibrate in Section 3. Section 4 presents quantitative experiments showing the model responses to net worth shocks. We introduce recapitalization policies and analyze their welfare effects in Section 5, and assess how these gains are affected by idiosyncratic risk in Section 6. Section 7 concludes.

2 The Model

We consider a closed economy composed by the household, financial and real sectors. Households work for firms in the real sector and deposit their savings with financial intermediaries. The financial sector intermediates households' savings by extending loans to firms producing goods in the real sector. The key element of the model is that both financial intermediaries and goods-producing firms are subject to financial frictions. We now proceed to formally describe the optimization problems faced by households and firms in the financial and real sector.

2.1 Real Sector Firms

The real sector (r superscript) is composed of a continuum of competitive firms with mass one. Each firm is managed by a risk-neutral entrepreneur that maximizes expected profits. Real sector entrepreneurs invest in productive capital k_t using their own net worth e_t^r and taking out loans l_t^r from financial entrepreneurs. They have access to a Cobb-Douglas production function combining capital and labor and returning revenues net of depreciation δ equal to

$$\left((1-\delta)k_t + k_t^{\alpha} n_t^{1-\alpha} - n_t W_t\right)\omega_{t+1}^r \tag{1}$$

where ω_{t+1}^r is a mean one idiosyncratic shock with cumulative distributive function Ω^r, W_t is the competitive market wage, and n_t is the amount of labor hired from the household sector.[2] The optimal demand for labor is given by

$$n_t^* = k_t \left(\frac{1-\alpha}{W_t}\right)^{1/\alpha} \tag{2}$$

which, if substituted out, allows us to rewrite expected net revenues in equation (1) as

$$k_t \overbrace{\left(\daleth + \alpha\left(\frac{1-\alpha}{W_t}\right)^{(1-\alpha)/\alpha}\right)}^{A_t} \tag{3}$$

where A_t is the expected return to capital common to all entrepreneurs because it does not depend on any firm specific variable, and $\daleth = 1-\delta$.

As in Carlstrom and Fuerst (1997) and Bernanke, Gertler and Gilchrist (1999), we introduce financial frictions through an agency problem caused by costly state verification *à la* Townsend (1979). In particular, external investors can observe the realization of the idiosyncratic shock ω_{t+1}^r only after paying a monitoring cost equal to a fraction μ^r of their loan. As shown by Douglas Gale and Martin Hellwig (1985) and Stephen Williamson (1987), the optimal contract in this setting involves risky debt, with financial entrepreneurs monitoring real sector entrepreneurs only if they

[2] Notice that we assume that idiosyncratic risk affects profits rather than revenues as it would under a traditional productivity shock interpretation. This is done for two reasons: first, it allows us to preserve linearity of the problem, facilitating aggregation as it will be seen momentarily, and second, it means the wage is not affected by the idiosyncratic risk since workers collect it before the shock is realized.

declare to be insolvent.[3] This happens any time liabilities exceed assets:

$$l_t^r(1+r_t^r) \geq k_t A_t \omega_{t+1}^r \tag{4}$$

or in other words any time the idiosyncratic shock ω_{t+1}^r is lower than

$$\underline{\omega}^r = \frac{l_t^r(1+r_t^r)}{k_t A_t} \tag{5}$$

where r_t^r is the firm-specific interest rate. This rate has to ensure an expected return to financial intermediaries equal to the average market return r_t

$$(1+r_t) = (1-\mu^r)\int_0^{\underline{\omega}^r} \frac{k_t}{l_t^r} A_t \omega^r \mathrm{d}\Omega^r(\omega^r) + (1-\Omega^r(\underline{\omega}^r))(1+r_t^r) \tag{6}$$

where the first and second terms on the right-hand side capture respectively the return to financial intermediaries if the real sector firm goes bankrupt or is solvent.[4]

The entrepreneur's objective is to maximize the expected profit

$$e_t^r \overbrace{\int_{\underline{\omega}^r}^{\infty} \left(\frac{k_t}{e_t^r} A_t \omega^r - \frac{l_t^r}{e_t^r}(1+r_t^r)\right) \mathrm{d}\Omega^r(\omega^r)}^{\Pi_t^r} \tag{7}$$

subject to definition (5) and the constraint (6). As shown in Bernanke, Gertler and Gilchrist (1999), this optimization problem boils down to choosing optimal leverage $\lambda_t^r = k_t^r/e_t^r$, which maximizes the expected profit rate Π_t^r given the ratio $A_t/(1+r_t)$.[5] Note that expected profits are concave in leverage due to the increasing risk of default and the borrowing cost r_t^r. Quite importantly for the tractability of the general equilibrium solution, optimal leverage is not a function of internal equity e_t^r because of the assumption of linear investment and monitoring technology. This implies that all

[3] A technical aspect worth clarifying is that the financial contract is not well-defined at zero net worth. For this reason, we do assume as in Carlstrom and Fuerst (1997) that banks and firms receive a small transfer from the household sector when they become insolvent. Since this transfer can be infinitesimally small, it does not alter the aggregate dynamics of the model. Indeed, since the solution procedure involves keeping track only of aggregate net worth in each sector, this transfer is effectively set to zero in our solution code.

[4] The average market return r_t will be determined in equilibrium and is the return earned by financial intermediaries on a fully diversified lending portfolio.

[5] This follows simply from the fact that Equation (6) can be expressed in terms of spreads (or ratios) relative to A_t. Similarly, Equation (7) can also be normalized in the same way, resulting in an equivalent problem in which the key argument is the ratio $A_t/(1+r_t)$.

firms have equal leverage, so that we have to include in the model's state space only the aggregate equity in the real sector E_t^r, instead of the entire distribution of equity across firms.

After the idiosyncratic shock ω_{t+1}^r is realized, solvent entrepreneurs distribute a share $\mathfrak{D}^r$ in dividends to the household.[6] This dividend distribution assumption is needed to rule out complete self-financing of the real sector which would make financial frictions irrelevant.

Summing up and focusing on the aggregate dynamics of the real sector, entrepreneurs observe at the beginning of the period their net worth e_t^r and based on the cost of borrowing r_t and the return on investment A_t choose the optimal leverage λ_t^r. The fact that leverage is common across firms implies that aggregate borrowing and investment in the real sector (denoted by upper case variables) are simply given by:

$$L_t^r = E_t^r(\lambda_t^r - 1) \tag{8}$$

$$K_t = E_t^r \lambda_t^r \tag{9}$$

Dividends for the household are equal to

$$\chi_t^r = \mathfrak{D}^r E_t^r \Pi_t^r \tag{10}$$

where we use the law of large numbers to write ex-post returns Π_t^r as the average across idiosyncratic risk realizations. Finally, aggregate net worth in the real sector evolves according to

$$E_{t+1}^r = (1 - \mathfrak{D}^r) E_t^r \Pi_t^r - \Upsilon_{t+1}^r \tag{11}$$

where Υ_{t+1}^r denotes aggregate net worth shocks.[7] These shocks should not be interpreted necessarily as changes in physical quantities, since they can also reflect in reduced form the impact on net worth

[6] In Bernanke, Gertler and Gilchrist (1999) $\mathfrak{D}^r$ is the fraction of entrepreneurs who die in each period who consume their net worth at the moment of death. We instead assume that money flows back to the household so that there is a unique value function in the model that is used to assess the welfare gains from recapitalization.

[7] These shocks are analogous to those used in Gertler and Karadi (2010), Mark Gertler, Nobuhiro Kiyotaki and Albert Queralto (2011), Markus K. Brunnermeier and Yuliy Sannikov (2010), and François Gourio (2012). Instead of using shocks that produce a net reduction in net worth, we could have considered redistributive shocks as in Matteo Iacoviello (2011) which move net worth across sectors. The qualitative results of the paper will be unchanged, but the quantitative implications of the model could differ. For example, to match a given reduction in GDP we would need to rely on a larger shock if it is redistributive, rather than involving a net reduction in net worth. Simulations based on redistributive shocks are available upon request to the authors.

from shocks to asset values. We preferred not to introduce explicit shocks to asset values since their realization would trigger an immediate increase in bankruptcies that would instantaneously pass losses to the lenders. This would confound whether the ensuing economic dynamics results from losses on borrowers or lenders. By considering net worth shocks that hit at the end of the period after debts have been repaid, we prevent this immediate spreading of losses and can better differentiate the impact of shocks to specific sectors.

2.2 Financial sector

The financial sector (f superscript) is modeled in the same way as the real sector, with the exception that external financing is raised from households (rather than from financial intermediaries) and that resources are lent to real sector firms (rather than invested in final production). Financial entrepreneurs use their own net worth e_t^f and the deposits raised from workers d_t^f to lend funds $l_t^f = e_t^f + d_t^f$ to firms in the real sector. Revenues from lending are given by:

$$l_t^f (1 + r_t) \omega_{t+1}^f \tag{12}$$

where ω_{t+1}^f is a mean-one idiosyncratic shock with cumulative distributive function Ω^f, and r_t is the average market return on loans to the real sector after averaging across all loans. We can interpret these shocks as reflecting managerial ability in collecting loans. Note that r_t is a safe return since financial entrepreneurs are assumed to fully diversify their lending, thus insuring against idiosyncratic shocks in the real sector. Furthermore, r_t is also independent from aggregate shocks to the net worth of the real sector since they are realized after loans have been repaid.

The same agency problem described for real sector entrepreneurs applies to entrepreneurs in the financial sector. Financial firms become insolvent if the idiosyncratic shock ω_{t+1}^f is lower than

$$\underline{\omega}^f = \frac{d_t^f (1 + i_t^f)}{l_t^f (1 + r_t)} \tag{13}$$

where i_t^f is the firm-specific interest rate which needs to ensure an expected return to the lender (i.e. depositors) equal to the risk-free return i_t that households gain by fully diversifying their deposits. This participation constraint requires

$$(1+i_t) = (1-\mu^f)\int_0^{\underline{\omega}^f} \frac{l_t^f}{d_t^f}(1+r_t)\omega^f \mathrm{d}\Omega^f(\omega^f) + (1-\Omega^f(\underline{\omega}^f))(1+i_t^f) \tag{14}$$

where the first and second terms on the right-hand side capture respectively the return to depositors if the financial intermediary goes bankrupt or is solvent.

The entrepreneur's objective is to choose leverage $\lambda_t^f = l_t^f/e_t^f$ as to maximize the expected profit

$$e_t^f \overbrace{\int_{\underline{\omega}^f}^{\infty} \left(\frac{l_t^f}{e_t^f}(1+r_t)\omega^f - \frac{d_t^f}{e_t^f}(1+i_t^f)\right) \mathrm{d}\Omega^f(\omega^f)}^{\Pi_t^f} \tag{15}$$

subject to definition (13) and the constraint (14). Optimal leverage is only a function of the ratio $(1+r_t)/(1+i_t)$ and is thus common to all entrepreneurs. Therefore, we only have to keep track of aggregate net worth E_t^f in the financial sector to solve for the model dynamics. After the realization of the idiosyncratic shock ω_{t+1}^f, solvent entrepreneurs repay their debt to depositors and then distribute a share $\mathfrak{D}^f$ of their net worth in dividends to households.

The aggregate dynamics of the financial sector are analogous to those of the real sector. Aggregate borrowing and lending are given by:

$$D_t^f = E_t^f(\lambda_t^f - 1) \tag{16}$$

$$L_t^f = E_t^f \lambda_t^f \tag{17}$$

After the realization of the idiosyncratic shocks and the repayment of deposits, financial entrepreneurs distribute dividends to households equal to

$$\chi_t^f = \mathfrak{D}^f E_t^f \Pi_t^f \tag{18}$$

Finally, next period net worth is given by

$$E_{t+1}^f = (1-\mathfrak{D}^f)E_t^f \Pi_t^f - \Upsilon_{t+1}^f \tag{19}$$

where Υ^f_{t+1} is an aggregate net worth shock affecting the financial sector.

2.3 Equilibrium in the financial and real sectors

Before closing the model with the household sector, it is useful to describe the equilibrium in credit markets for a given level of the risk-free deposit rate i_t. In equilibrium, the marginal product of capital, A_t, is determined by the total amount of capital that is used in production by all entrepreneurs. The assumption of competitive markets and the constant returns to scale production function at the individual level ensures that the aggregate production function is simply $K_t^\alpha N^{1-\alpha}$, where N denotes the aggregate and fixed labor supply, implying that $A_t = \left(\daleth + \alpha K_t^{\alpha-1}\right)$. Considering that the real sector leverage is exclusively a function of $A_t/(1+r_t)$, for a given r_t and E_t^r, the equilibrium return on capital, A_t, is thus given by the solution to $A_t = \daleth + \alpha(E_t^r \lambda^r(A_t/(1+r_t)))^{\alpha-1}$.

With this solution on hand, the amount of loans demanded by the real sector, L^r, is a function of the amount of equity in the real sector and the average market return on loans demanded by the financial sector, $L^r(E_t^r, r_t) = E_t^r(\lambda^r(A(E_t^r, r_t)/(1+r_t)) - 1)$, where $A(E_t^r, r_t)$ is the equilibrium return on capital obtained above. Similarly, the financial sector optimal leverage only depends on $(1+r_t)/(1+i_t)$, and the supply of loanable funds, L^f, is a function of r_t, i_t, and E^f, $L^f(E_t^f, r_t, i_t) = (\lambda^f(r_t/(1+i_t))E_t^f$.

For a given risk-free rate, i_t, and capitalization levels in the financial and real sector, E_t^f, E_t^t, the equilibrium risk-free lending rate, r_t, solves $L^r(E_t^r, r_t) = L^f(E_t^f, r_t, i_t)$. Note that the state space of the model thus boils down to the triplet E_t^r, E_t^f, and i_t.

2.4 Household sector

The household sector (h superscript) is composed by a continuum of identical households with mass one who maximize the present discounted value of consumption c_t^h under a CRRA utility function with risk aversion coefficient γ. Households supply labor inelastically to the real sector, deposit savings d_t with financial intermediaries, and receive dividends from both real χ_t^r and financial χ_t^f entrepreneurs. We have chosen to fix the labor supply because its dynamics would make the sources of welfare gains from recapitalization policies less transparent, for reasons explained later on. Each household's net worth, e_t^h , evolves according to:

$$e_{t+1}^h = \overbrace{(e_t^h - c_t^h)}^{d_t^h}(1+i_t) + \chi_t^r + \chi_t^f + W_t - \Upsilon_{t+1}^h \tag{20}$$

where d_t^h is the supply of deposits, W_t is the market competitive wage, and Υ_{t+1}^h is an aggregate shock affecting household wealth analogous to the net worth shocks to the financial and real sectors. Note that the rate of return earned on deposits i_t is riskless since households diversify deposits across financial intermediaries to insure against idiosyncratic risk in the financial sector.[8] This return is also protected from aggregate risk since we assume that aggregate shocks to the net worth of financial intermediaries are realized after deposits have been honored.

The household's value function can be written as follows

$$V^h(e_t^h, \mathbf{s_t}) = \max_{\{c_t\}} \left\{ u(c_t^h) + \beta \mathbb{E}_t \left[V^h(e_{t+1}^h, \mathbf{s_{t+1}}) \right] \right\} \tag{21}$$

$$\text{s.t.}$$

$$e_{t+1}^h = (\overbrace{(e_t^h - c_t^h)}^{d_t^h}(1+i_t) + \chi_t^r + \chi_t^f + W_t) - \Upsilon_{t+1}^h \tag{22}$$

where β is the intertemporal discount factor and $\mathbf{s}$ denotes the state space. Considering that households are identical and not subject to idiosyncratic risk, the state space includes the aggregate net worth in each sector, E^f, E^r, and E^h, whose evolution, for clarity, is reproduced below.

$$E_{t+1}^h = \overbrace{(E_t^h - C_t^h)}^{D_t^h}(1+i_t) + \chi_t^r + \chi_t^f + W_t - \Upsilon_{t+1}^h \tag{23}$$

$$E_{t+1}^f = (1-\mathfrak{D}^f)E_t^f \Pi_t^f - \Upsilon_{t+1}^f \tag{24}$$

$$E_{t+1}^r = (1-\mathfrak{D}^r)E_t^r \Pi_t^r - \Upsilon_{t+1}^r \tag{25}$$

[8]This can be thought of as a mutual fund investment.

2.5 Competitive Equilibrium and Sequence of Events

A competitive equilibrium is defined by stochastic sequences of choice variables $[C_t, \lambda_t^f, \lambda_t^r]_0^\infty$, state variables $[E_{t+1}^h, E_{t+1}^r, E_{t+1}^f]_0^\infty$, and prices $[W_t, i_t, r_t]_0^\infty$ such that given the initial conditions (E_0^h, E_0^r, E_0^f): (i) households chooses consumption to maximize the expected present discounted value of utility, subject to (22), taking as given wages and the expected return on deposits; (ii) the financial entrepreneurs choose leverage to maximize (15), taking as given the expected return on deposits demanded by households and the expected return on loans, subject to (14); (iii) the real sector entrepreneurs choose leverage to maximize (7), taking as given the expected return on loans demanded by financial sector entrepreneurs and the expected return on capital, subject to (6); (iv) the aggregate state evolves according to (23), (24), and (25); (v) markets clear, which implies that the expected return on deposits satisfies $D_t^h = E_t^f(\lambda^f - 1)$, the expected return on loans satisfies $L^r = L^f$, wages satisfy Equation (2) with $n^* = 1$ because labor supply is fixed, and the return on capital satisfies $A_t = \urcorner + \alpha(E_t^r \lambda^r)^{\alpha-1}$.

Figure 1 summarizes the sequence of events for the whole model. We solve the model with global solution methods building on Christopher D. Carroll (2006)'s method of endogenous gridpoints.

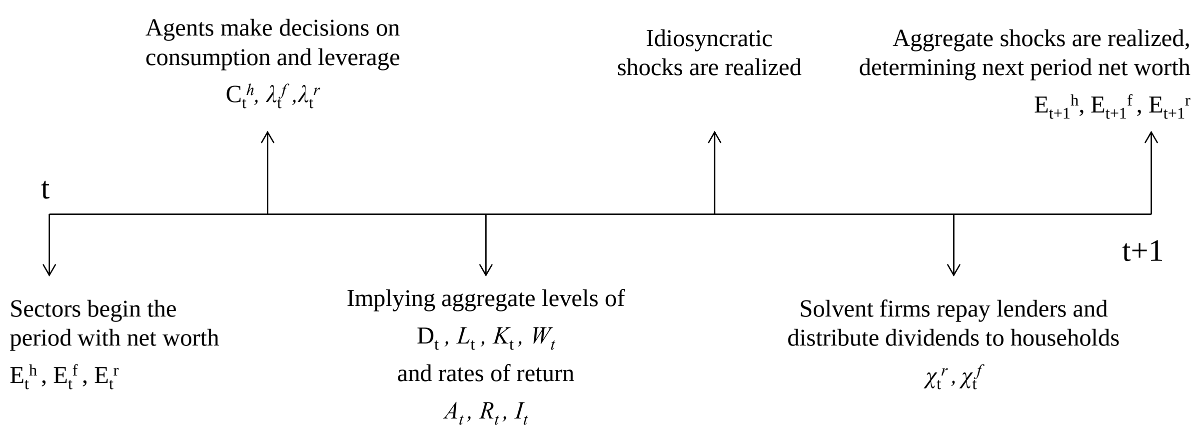

Figure 1: Sequence of events

3 Calibration

We calibrate the model at quarterly frequency setting the depreciation rate, δ, and share of capital, α, in the production function to standard levels of 2.5% and 36% respectively. The discount factor for the household is set equal to 0.994, which generates a steady state level for risk-free deposit rate i_t of roughly 2 percent in annual terms. We calibrate the remaining parameters to match statistics of leverage, borrowing spreads, and bankruptcies in the real and financial sectors in the deterministic steady state. This is computed as the point in the state space where the model converges to if no net worth shocks hit the economy. This is also the initial point from which all our impulse response functions originate.

Data show that financial and non-financial firms have somewhat different bankruptcy rates and risk spreads, but the greater source of difference is in leverage (Table 2). In our model, we could generate the differences in leverage by using a higher dividend rate in the financial sector, which would exogenously shrink its net worth. However, this would also artificially inflate the rate of return on financial firms and thus possibly the welfare gains from their recapitalization. Therefore, we constrain ourselves to use the same dividend rate in both the real and financial sectors, which leaves us with five parameters – the common dividend rate and each sectors' standard deviation of idiosyncratic shocks and size of monitoring costs – to match six moments, i.e. the financial and real sectors' leverages, spreads, and bankruptcy rates. This implies that to achieve higher leverage in the financial sector we need to reduce the extent of financial frictions on financial intermediaries, both in terms of monitoring costs and idiosyncratic risk. We set the monitoring costs in the financial and real sector to 0.12 and 0.36 respectively. In the context of the model, these are equivalent to bankruptcy costs and are within the range of values considered as empirically plausible (Carlstrom and Fuerst (1997)). We chose a mean-one lognormal distribution for idiosyncratic risk with standard deviations equal to 0.22 for the real sector and 0.06 for financial sector firms. Finally, the exogenous dividend rate is set at 4.7% in both sectors. The model parameters are summarized in Table 1 and the resulting steady state outcomes and data moments are shown in Table 2.

Regarding the calibration of the aggregate shock, we assume that each sector's net worth shock, $\Upsilon^h, \Upsilon^r, \Upsilon^f$ involves the same absolute loss equal to a proportion Φ of the total net worth in the economy $E^h + E^f + E^r$. Φ is set equal to 4% and is chosen so that when the net worth loss affects the financial sector, GDP falls by about 4% as experienced by the US in 2008Q4. Each of the shock is realized with probability 1 over 75. This implies that each sector is expected to receive a shock every 75 years, roughly equivalent to the time gap between the Great Depression and the Great Recession.

Table 1: Model Parameters

Parameter		Value
Depreciation rate	δ	2.5%
Share of capital	α	36%
Households discount factor	β	0.994
Monitoring costs in the financial sector	μ^f	0.12
Monitoring costs in the real sector	μ^r	0.36
Idiosyncratic risk in the financial sector	σ_ω^f	0.06
Idiosyncratic risk in the real sector	σ_ω^r	0.22
Dividend rate in the financial sector	$\mathfrak{D}^f$	4.7%
Dividend rate in the real sector	$\mathfrak{D}^r$	4.7%

Table 2: Steady state values and empirical counterparts

Variable	Model	Data
Leverage Financial Sector	7.5	6.6[1]
Leverage Real Sector	2.4	1.9[2]
Risk Spread Financial Sector	41 bps	76 bps[3]
Risk Spread Real Sector	127 bps	104 bps [3]
Bankruptcy Rate Financial Sector	3.0 %	2.1 % [4]
Bankruptcy Rate Real Sector	3.1 %	3.0 % [5]

[1] Average assets-to-market value for listed U.S. banking firms over the period 2002-2007
[2] United States Flow of Funds, Nonfarm Nonfinancial Corporate Business average for 2002-2007
[3] Average spreads on one-year BBB bonds over the period 2002-2007
[4] Market share of failed U.S. banks over the period 1985-2010
[5] Historic average of business failures Bernanke, Gertler and Gilchrist (1999)

Figure 2 shows how some key variables depend on the capitalization of the real and financial sectors using the calibrated parameters and setting the deposit rate i_t to its deterministic steady state level. Optimal leverage for real sector firms declines as net worth in the sector increases, since more net worth implies higher investment, higher capital, and thus lower returns which reduce the incentives to lever up. The real sector leverage is instead increasing in the net worth of the financial sector because the larger the supply of credit lowers the borrowing costs. Financial firms' leverage also decreases with net worth in the sector since larger net worth increases the supply of credit and reduces returns. The charts depicting the behavior of risk spreads show that they move in the same direction as leverage, since higher leverage implies higher default risk. Finally, the right-side charts show the evolution of capital and wages in the economy.

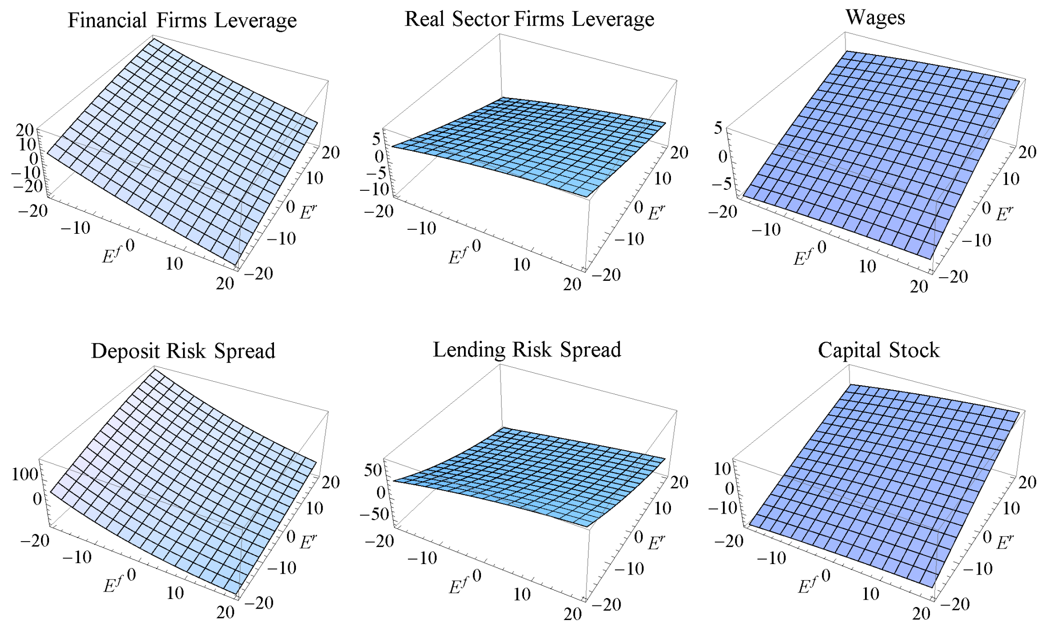

Figure 2: Equilibrium in the real and financial sector (% deviations from steady state)

4 Responses to net worth shocks

In this section we analyze the model responses to shocks that reduce the net worth in the household, financial and real sector. We begin by assessing in section 4.1 the potential of the financial sector in amplifying shocks originating in the real sector. We find negligible amplification effects since the intermediation margin in the financial sector remains fairly stable. But the financial sector can become itself a strong generator of shocks. In section 4.2 we show indeed that the economic disruption caused by a given aggregate destruction of net worth is much more severe if the losses are concentrated on the balance sheets of the financial sector rather than on the household and real sector.

4.1 Financial sector as amplifier

We examine how the presence of financial frictions on financial intermediaries changes the dynamic adjustment in the economy relative to a benchmark in which financial frictions are present only on real sector firms. [9] This benchmark is comparable to Bernanke, Gertler and Gilchrist (1999)

[9] In the context of our model, we can shut down financial frictions in the financial sector by either setting the monitoring cost μ^f or the variance of idiosyncratic shocks ω^f to zero. Without monitoring costs or idiosyncratic risk the model boils down to a frictionless one.

and Carlstrom and Fuerst (1997) in which the capitalization of the financial sector does not matter because financial intermediaries face no financial frictions. In conducting this experiment, we eliminate the possibility of aggregate shocks to the household and financial entrepreneur's net worth and solve the problem under the assumption that only the real sector is subject to such shocks. Figure 3 shows the resulting dynamics as a percentage deviation from the deterministic steady state for a subset of variables.

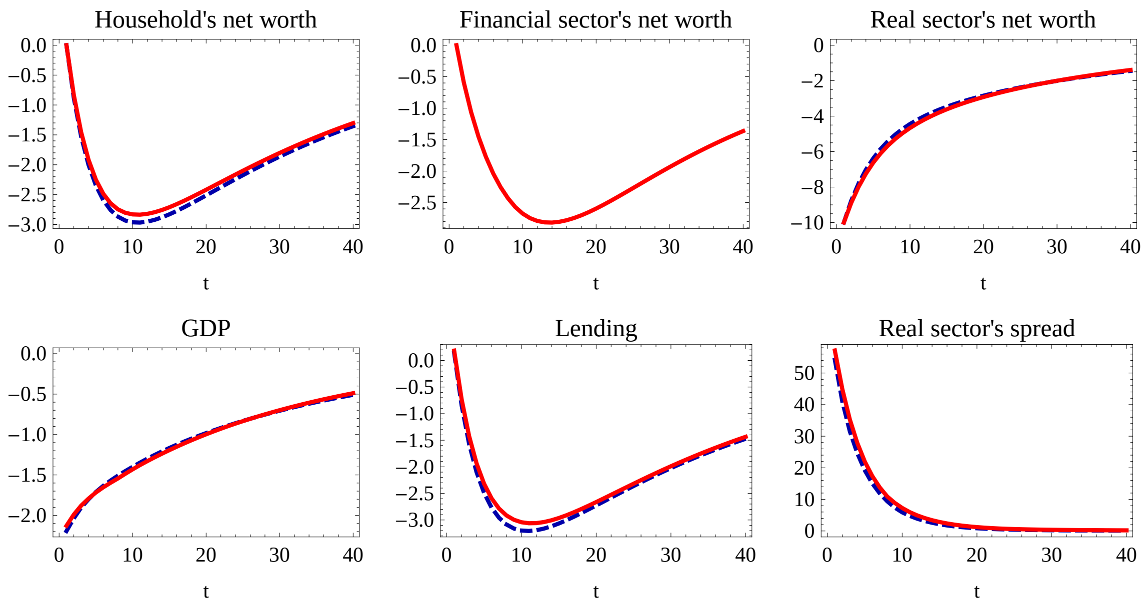

Figure 3: Shocks to real sector and amplification by the financial sector.
Note: Solid and dashed lines identify the responses with and without frictions in the financial sector respectively (% deviations from steady state.)

In absence of financial frictions in the financial sector, the borrowing rate for real sector firms includes a wedge over the rate of return on deposits determined only by the real sector's risk of default and bankruptcy costs. When we introduce financial frictions also in the financial sector, this wedge increases because the lender's risk of default and bankruptcy costs are now also priced. This effectively raises the cost of borrowing for the real sector and consequently lowers its leverage and the capital stock in the economy. Therefore, the introduction of frictions in the financial sector involves a change in the steady state. However, Figure 3 reveals that the responses to shocks in the real sector are virtually unchanged, at least for the baseline calibration. [10] This is essentially

[10] It is important to note however that our model does not incorporate endogenous asset prices, which in the financial accelerator literature is a key mechanism to generate quantitatively important amplification effects (Bernanke, Gertler and Gilchrist (1999) and others).

because the intermediation margin charged by the financial sector stays rather constant in response to disruptions in the real sector.

4.2 Financial sector as shock generator

In the previous section we have considered the role of the financial sector in amplifying shocks affecting the real sector. But the financial sector can itself be a source of shocks. More specifically, we now consider how the effects of a given reduction in aggregate net worth depend on the sector that is directly facing the losses. As discussed in the calibration of the model, we consider an exogenous reduction in total net worth of 4 percent and compare the impulse response functions of the model when this loss is allocated to the household, the financial, or the real sector. Figure 4 shows the resulting dynamics as a percentage deviation from the deterministic steady state of the model. The top row shows the evolution of net worth in each sector, the second row traces the responses in consumption, loans and output, and the third and fourth rows focus respectively on the financial and real sector by considering the risk-free borrowing rates, the borrowing spreads and the leverages. Each period of the simulation represents one quarter.

Consider first the responses when the net worth loss is concentrated on the real sector (dotted lines). These are similar to those considered in the previous section, but not identical since now the households' policy functions are solved taking into account the possibility of net worth shocks also on the household and financial sector. The fall in the capitalization of the real sector reduces invested capital and output and drives up the marginal return on investment. The real sector's leverage therefore increases leading to higher borrowing spreads. From the perspective of the household, the lower capitalization of the real sector implies lower future wages. In an effort to smooth consumption over time, households immediately reduces consumption which keeps falling over time. This is because households' net worth gradually shrinks due to lower wages and rates of return. The process of recovery is slow and characterized by a gradual de-leveraging of the real sector.

Let us now turn to the case in which the net worth shock is concentrated on the financial sector (solid lines). Note that the capitalization of the financial sector suffers a percentage loss much larger than the one experienced by the real sector when the shock hits the latter. This is because the financial sector's net worth is the smallest and its leverage is the highest, so that if an equal-size shock hits the financial sector it produces a much larger percentage reduction in capitalization. The capital loss leads to much higher leverage and borrowing spreads for the financial sector, whose ability to intermediate funds is severely impaired. The demand for deposit and supply for loans contract considerably leading to a strong reduction in the deposit risk-free rate and increase in the lending rate. Lower lending coupled with higher bankruptcies in the financial sector leads to a large contraction in GDP similar in magnitude to the 2008 US recession.

Finally, we consider the model responses if the net worth loss falls on the household sector (dashed lines). Lower household wealth implies lower deposits, lower lending and ultimately lower output. The reduction in output is however very moderate compared to when the shocks are concentrated on the financial and real sectors. This largely depends on the behavior of the rate earned on deposits. Shocks to the financial and real sectors reduce the deposit rate and thus discourage household saving which is needed to speed up the recovery. This is due to the presence of financial frictions which lead to an increase in spreads after net worth losses. Conversely, when the shock is concentrated on the household sector, the deposit rate increases and households respond by cutting consumption and supporting new investment.

The dynamics shown in Figure 4 are presented in deviations from steady state, with the fall in output approximating the largest 4-quarter cumulative decline in U.S. real GDP of 4.6 percent seen after the 2008 recession. To assess more clearly how the model performs in matching the financial variables, Table 3 compares the levels of few key variables in the model before and after the shocks with the empirical counterparts before and after the Great Recession. Overall, the model approximates fairly well the increase in leverage and risk spreads in the financial sector, as well as the decline in lending. Moreover, the exogenous 58 percent loss in financial sector net worth is fairly close to the observed decline in the market value of banking firms, equal to 65 percent from peak to trough. The model does not generate the observed increase in the real sector's leverage, but the changes in real sector leverage are small both in the data and in the model. Similarly, the model does not replicate the increase in the real sector's risk spreads that is likely the result of flight to quality not captured in the model. Indeed, since leverage in the real sector changed little during the crisis, the observed increase in spreads was likely the result of investors moving away from risky securities.

Summing up, the model responses reveal that output losses are much more pronounced if a given

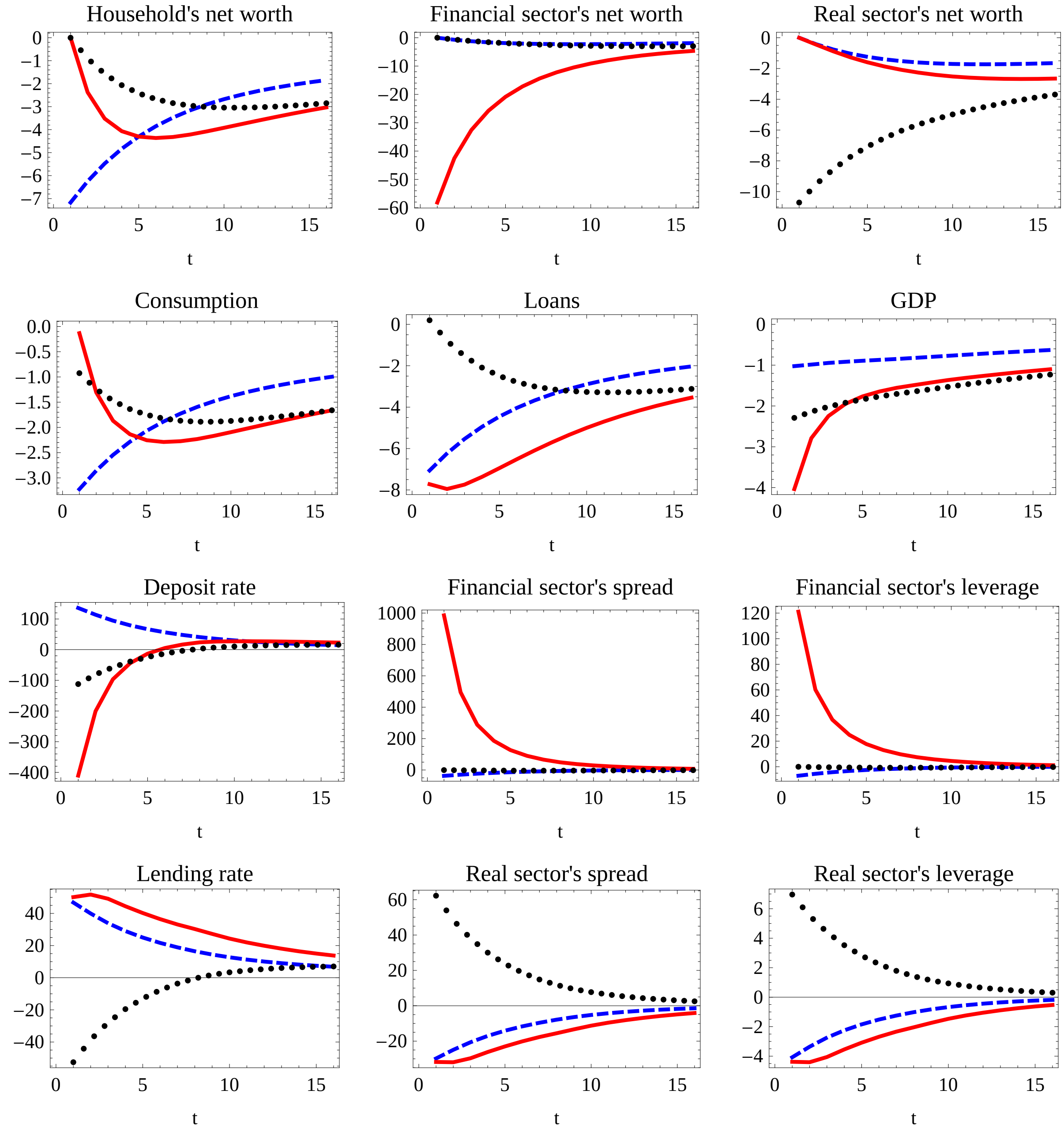

Figure 4: Impulse response functions to net worth shocks
Note: Shocks to the net worth of the household (dashed), financial (solid), and real (dotted) sectors (% deviations from the steady state)

net worth loss is concentrated on the highly leveraged financial sector. This observation provides the motivation for policies targeted to recapitalize the financial sector after a negative shock.

Table 3: Changes in key financial variables.

	Before shock[1]		After shock[2]	
Variable	Data	Model	Data	Model
Financial sector's leverage	6.58	7.53	14.94	16.66
Real sector's leverage	1.85	2.39	1.99	2.28
Financial sector's risk spread (bps)	76	41	479	463
Real sector's risk spreads (bps)	104	127	482	86
Loans growth rate (%)	1.21	0	-5.59	-7.72
Financial sector's net worth loss (%)			-65.34	-58.17

[1] Average for the period 2001q1-2007q4 for data and steady state values for the model
[2] Largest or lowest value reached, depending on direction of change. For data, computed over 2008-2010 period, except for financial sector net worth loss, which is computed as the decline in aggregate market value from peak to trough of listed U.S. commercial banks with more than US$ 1 billion in assets; for the model, computed over the simulated data from the realization of the financial shock.

5 Recapitalization policies

How large are the potential welfare gains from recapitalizing the financial sector after a negative net worth shock? Can recapitalization funds be taken from the real sector or only from the household sector? How do gains vary with the size of the shock? We address these questions by comparing the household's welfare under different recapitalization policies. These recapitalizations may take different forms, including government equity injections, debt-to-equity conversion, asset swaps at above market rates, or simply overly lax monetary policy for a prolonged period of time. All of these interventions, which have been put in practice in the recent and many other crises (Luc Laeven and Fabian Valencia (2012*b*)) involve a transfer of wealth from savers to borrowers and alleviate the increase in the wedge that arises between the cost of borrowing and the return on lending, which is the source of the inefficiency of the competitive equilibrium. In this section, we compare welfare when we implement these wealth transfers in response to shocks, without taking a stand on the particular form of implementation. However, we have chosen to model these transfers as resembling direct equity injections because there is empirical evidence suggesting that this way of implementation supports output growth and that they have a stronger effect than other alternatives (Luc Laeven and Fabian Valencia (2012*a*), Mariassunta Giannetti and Andrei Simonov (2011)). Nevertheless, comparing in detail the effectiveness of alternative implementation options becomes worthwhile only after establishing that the potential welfare gains from recapitalizations are reasonably large.

Note that in our model the introduction of recapitalization policies does not generate moral hazard leading to further banks' risk taking.[11] We believe that moral hazard is likely to be relatively small as long as recapitalizations are used exclusively in response to rare but large aggregate shocks. Managers and shareholders should indeed still be disciplined in their leverage decisions by the idiosyncratic shocks which remain uninsured. Furthermore, recapitalizations can be designed as to involve considerable losses for banks' managers and shareholders. In any case, analyzing the extent to which moral hazard can limit the benefits from recapitalization policies is not particularly interesting without first establishing that the potential gains from recapitalizations are substantial.

To assess welfare in the presence of recapitalization policies, we solve for the households' value function under the expectation that the financial sector will be fully recapitalized in case of a net worth shock. Recapitalization funds may come from the household sector, from the real, or from both. We express welfare gains as the permanent percentage increase that households would require to voluntary remain in a world without recapitalization. This is computed by solving for the ν such that:

$$(1+\nu)^{1-\gamma} v^h(E^h, E^f, E^r) = \tilde{v}^h(\tilde{E}^h, \tilde{E}^f, \tilde{E}^r) \tag{26}$$

where tilde denotes variables in the presence of recapitalization. Regarding where in the state space to compare welfare, we will consider two cases. First, we compute the welfare gains at the determinist steady state without recapitalization policies, defined as the point in the state space the model converges to if not disturbed by net worth shocks. These can be thought of as the gains from "introducing" recapitalization policies in an economy that has not had them so far. Second, we assess the welfare gains evaluating the value functions with and without recapitalizations at their own deterministic steady states. So we will compare welfare at the deterministic steady state for the model without recapitalization with welfare at the steady state in an economy with recapitalization policies. This captures the gains from "having" recapitalization policies.

The welfare gains from the full recapitalization of the financial sector are plotted in Figure 5 as a function of the recapitalization share financed by the household sector, with the remaining

[11] This is because the maximization problem solved by financial intermediaries is linear and aggregate shocks do not affect borrowing spreads since they are realized after the within-period debt is repaid.

proportion being financed by the real sector. The dashed and solid lines refer respectively to the comparison at the non-recapitalization steady state and at each value function's steady state. Considering first the gains at the non-recapitalization steady state, we observe that if the financial sector is entirely recapitalized with funds from the household sector, the welfare gains are equivalent to a permanent increase in consumption of 0.12%. To put this number into context, these gains are similar to those derived by Robert E., Jr. Lucas (1987) from the elimination of the US business cycle. We do not want to enter the debate on whether these gains are small or large, but we simply want to highlight that recapitalization polices in response to large financial shocks are equally deserving of consideration as policies to reduce business cycle fluctuations. The model implies indeed that the potential gains from recapitalizing the financial sector in case of large but rare net worth shocks (occurring in our calibration only every 75 years) could lead to gains as large as those from removing business cycle fluctuations.

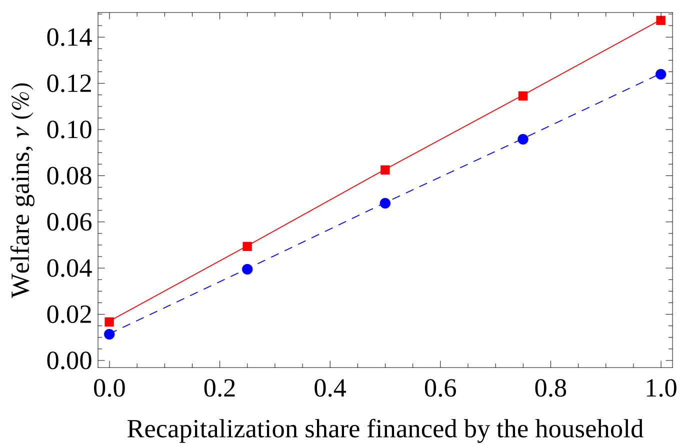

Figure 5: Welfare gains from the full recapitalization of the financial sector.
Note: The gains are expressed as a function of the recapitalization share financed by the household sector, with the remaining proportion being financed by the real sector. The dashed and solid lines respectively identify the gains from "introducing" and "having" recapitalization policies.

Figure 5 also shows that the gains from recapitalization are decreasing if the household provides a lower share of the recapitalization funds which are thus taken from the real sector. Interestingly the gains from recapitalizing the financial sector remain positive even if the recapitalization is entirely financed by subtracting resources to the real sector. This may seem counterintuitive since the purpose of the recapitalization is ultimately to support investment by the real sector. The difference in leverage between the two sectors explains the result. The much higher leverage in the financial sector, particularly after a negative net worth shock, implies that funds moved from the real to the financial sector are able to support much more lending and thus increase final investment. Furthermore, the recapitalization of the financial sector reduces bankruptcies among financial intermediaries and allows for a faster re-accumulation of aggregate capital.

Let us now turn to compare welfare at the steady states of economies with and without recapitalization policies (solid line, Figure 5). Welfare gains are now even somewhat larger, essentially because the presence of recapitalization policies moves the economy to a higher steady state level of net worth in all sectors. At a first glance, this may seem surprising since recapitalization policies should reduce households' precautionary savings by removing the risk of wage reduction during financial crisis. This is indeed the case, but recapitalizations also eliminate the big decrease in the risk-free deposit rate associated with net worth shocks on financial intermediaries.[12] As a consequence, the expected higher return on savings stimulates capital accumulation and moves the economy towards a steady state with higher welfare. This is a second channel through which the adoption of recapitalization policies can improve welfare.

The gains in Figure 5 have been computed imposing the full recapitalization of the financial sector. Figure 6 considers instead the case of partial recapitalization by showing how the gains vary with the proportion of the financial sector's net worth that is replenished through the recapitalization. The left-side chart shows that if the recapitalization funds are subtracted from the household sector, a full recapitalization is preferable.[13] If instead the recapitalization is financed with resources from the real sector, the right-side chart reveals that a partial recapitalization is preferable. Subtracting excessive resources from the real sector leads indeed to a strong increase in the real sector leverage and borrowing wedge whose costs may be larger than the benefits from recapitalizing the financial sector.

It is also instructive to consider how the welfare gains vary with the size of the net worth shock. Figure 7 traces the welfare gains from fully recapitalizing the financial sector with funds taken from

[12] Note that the knowledge that shocks affecting the financial sector will be passed to the household through recapitalization policies reduces the expected rate of return on savings. However, this negative impact on expected returns is more than compensated from avoiding the negative real interest rates that would be associated with a financial crisis.

[13] Note that when the recapitalization is financed by the household sector the welfare gains can increase even if the recapitalization exceeds the size of the financial sector's net worth loss. This is because the model's steady state is inefficient due to the presence of financial frictions, so that welfare may increase by pushing the financial sector's net worth above its steady state. This source of gains pertains, however, to a modification of the steady state, rather than to the recapitalizing the financial sector in response to a given capital loss.

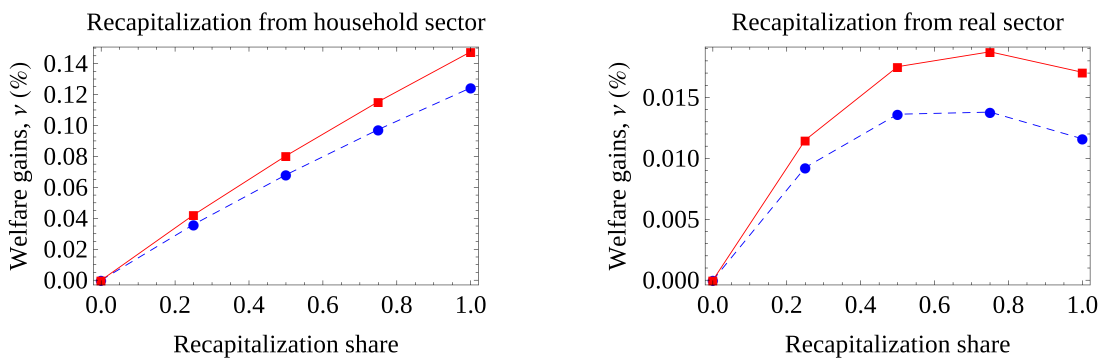

Figure 6: Welfare gains from partial recapitalization.
Note: The dashed and solid lines respectively identify the gains from "introducing" and "having" recapitalization policies.

the household sector. Gains are again presented by comparing welfare at the non-recapitalization steady state (dashed) and at each value function's steady state (solid). We observe that the gains are exponentially increasing in the size of the shock. This result is relevant to think about the merit of recapitalization policies if there are costs associated with transferring resources across sectors. We have so far neglected that implementing recapitalization policies can be costly, since they could create distortions and require the creation of public agencies to administer the recapitalization process. In so far as these costs involve a fixed component, recapitalization policies should thus be confined to respond only to large shocks.

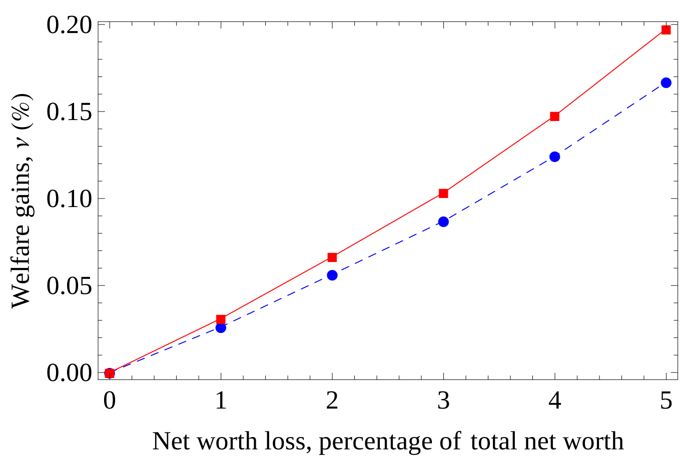

Figure 7: Welfare gains from full recapitalization as a function the net worth loss.
Note: The dashed and solid lines respectively identify the gains from "introducing" and "having" recapitalization policies.

The exact quantification of the potential distortions and inefficiencies caused by recapitalizations is beyond the purpose of our analysis and would be contingent on the particular implementation mechanism for the recapitalization. However, the following simple exercise suggests that recapitalization policies would be welfare enhancing even if they involve considerable inefficiencies. Let us assume that for each unit of funds transferred from the household to the financial sector, a certain proportion is lost. Figure 8 shows the welfare gains from attempting a full recapitalization as a function of the proportion of the recapitalization funds that is lost in the transfer. We observe that the recapitalization of the financial sector leads to positive welfare gains even if more than half of the recapitalization funds are lost.

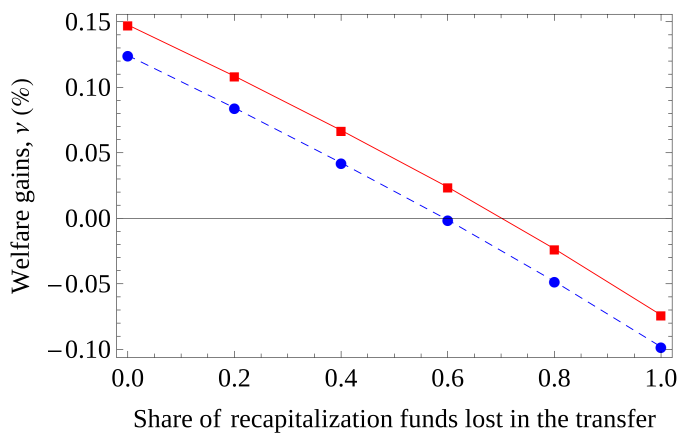

Figure 8: Welfare gains from recapitalization as a function of the funds lost in the transfer.
Note: The dashed and solid lines respectively identify the gains from "introducing" and "having" recapitalization policies.

In Section 2.4 we deferred an explanation of why we opted for fixed rather than endogenous labor supply. The reason is that an endogenous labor supply would further increase the welfare gains of recapitalizing the financial for two reasons. First, with endogenous labor the wage reduction after the net worth shock to the financial sector would induce a decline in labor supply and a more severe GDP contraction. The recapitalization would thus generate additional gains since by supporting investment and wages it would contain the reduction in labor supply. Second, when the recapitalization is financed with funds from the household, it generates the negative wealth effect that the referee refers to and thus would further stimulate labor supply. Given the focus of this paper on the role of financial frictions, we prefer to keep labor fixed so that the welfare gains arise solely from the mitigation of financial frictions, at the cost of possibly underestimating them.[14]

[14]Controversies about the elasticity of labor supply are a second reason why we preferred to leave this mechanism aside.

6 Uncertainty shocks

In our model, idiosyncratic risk is a key ingredient in generating agency costs, since the latter arise from the interplay between the costly monitoring of projects and the risk of bankruptcy. We now turn to examine the dynamic responses in our model to changes in idiosyncratic risk in the financial sector. Recent literature has discussed the importance of uncertainty shocks similar to those we consider and argued that they contribute importantly to business cycle fluctuations. Some examples include: Christiano, Motto and Rostagno (2009), Bloom, Floetotto and Jaimovich (2011), Gilchrist, Sim and Zakrajšek (2010), and Arellano, Bai and Kehoe (2011).

Figure 9 depicts the dynamic responses of the model following a permanent increase (solid line) and decrease (dashed line) in idiosyncratic uncertainty in the financial sector equivalent to 20 percent of the baseline standard deviation. In absence of limited liability in the financial sector, the change in its idiosyncratic risk would be inconsequential given the linearity of the financial entrepreneur's problem. However, limited liability implies that variations in idiosyncratic risk lead to changes in default rates.

Consider for instance the case of a decrease in idiosyncratic risk. The lower risk of default implies that the spread on financial intermediaries' borrowing rates decreases. With lower borrowing costs, financial intermediaries find it profitable to increase leverage and lending. The latter effect increases the demand for deposits which discourages consumption and stimulates household savings by pushing the risk-free rate up. Higher lending in turn pushes down the borrowing costs for firms in the real sector which lever up as well. Consequently, the capital stock and output rise. Note that net worth in the financial sector gradually decreases. This is because limited liability implies that changes in idiosyncratic risk affect only the upside returns. Therefore, lower idiosyncratic risk reduces profitability which leads to lower capitalization. In contrast, net worth in the real sector increases since profitability goes up thanks to the lower borrowing costs. All these effects carry through symmetrically when the shock is an increase in idiosyncratic uncertainty.

One interesting implication of this exercise is that a reduction in idiosyncratic uncertainty increases leverage in the financial sector, which in turn increases its vulnerability to aggregate shocks. It is useful to draw a parallel between this exercise and what happened prior to the crisis that started in the U.S. in 2007. The reduction in idiosyncratic uncertainty in our model could be interpreted as the impact of financial innovation. For instance, the increasing use of credit default swaps and securitization that grew rapidly over the decade that preceded the crisis had precisely the effect of reducing idiosyncratic risk. Over this same period, we witnessed a significant increase in leverage, which in turn increased the economy's vulnerability to systemic risk, or aggregate shocks. The outcome of the simulation performed here is consistent with these stylized facts.

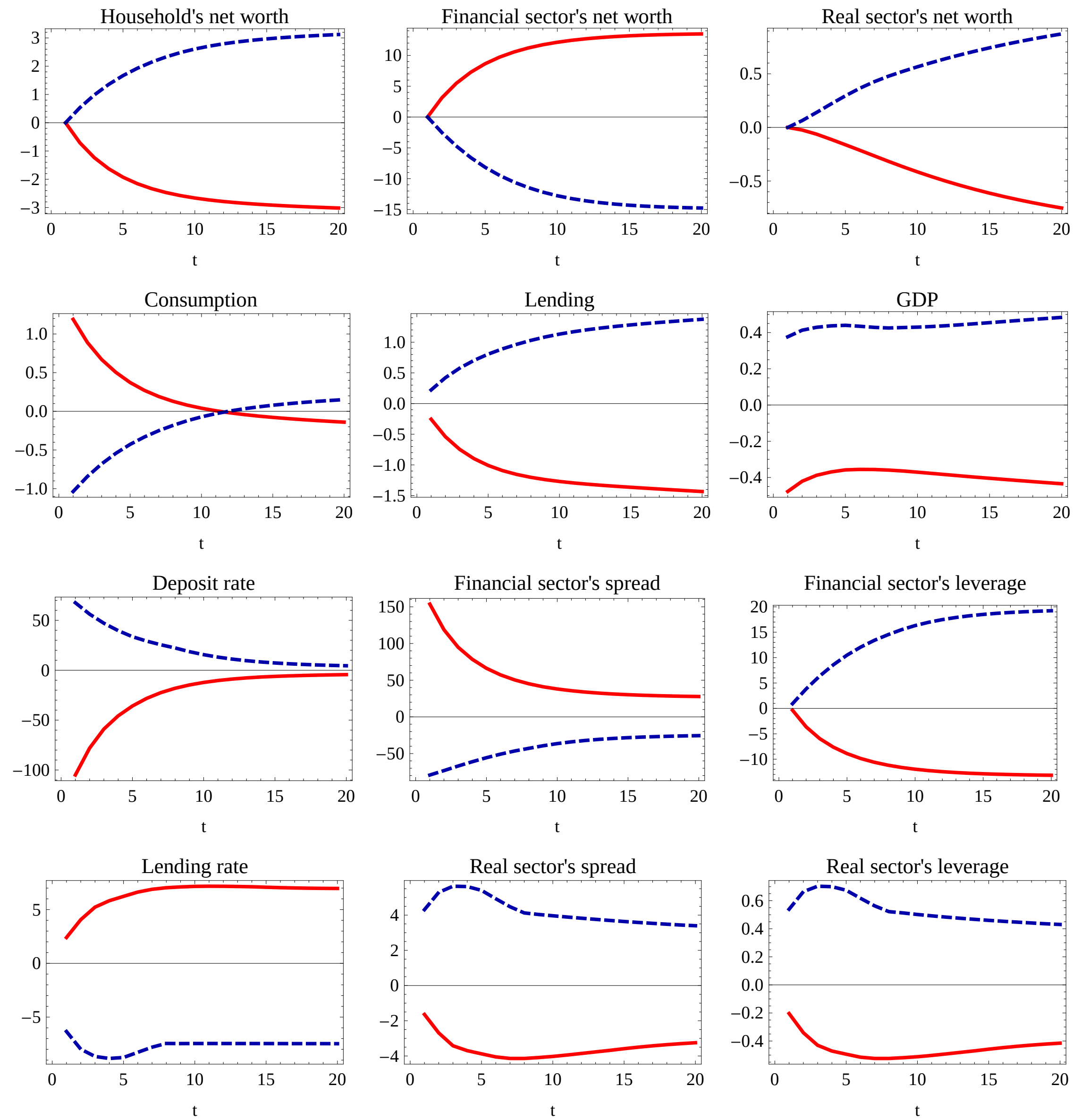

Figure 9: Impulse response functions to changes in idiosyncratic risk
Note: Solid and dashed lines identify respectively the responses to a 20% increase and decrease in idiosyncratic risk in the financial sector (% deviations from the steady state)

6.1 Recapitalization Policies and Idiosyncratic Risk

We now re-examine the welfare gains obtained earlier with the goal of studying how they vary with idiosyncratic risk. Notice that on the one hand, one would expect the recapitalization of the financial sector to become less relevant as we approach zero idiosyncratic risk in the financial sector because at that point financial frictions in the sector become irrelevant. However, as shown in the previous section, lower idiosyncratic risk implies higher leverage which increases the vulnerability of the economy to aggregate shocks. The impact of changes in idiosyncratic risk on the welfare gains from recapitalization policies is thus ex-ante ambiguous.

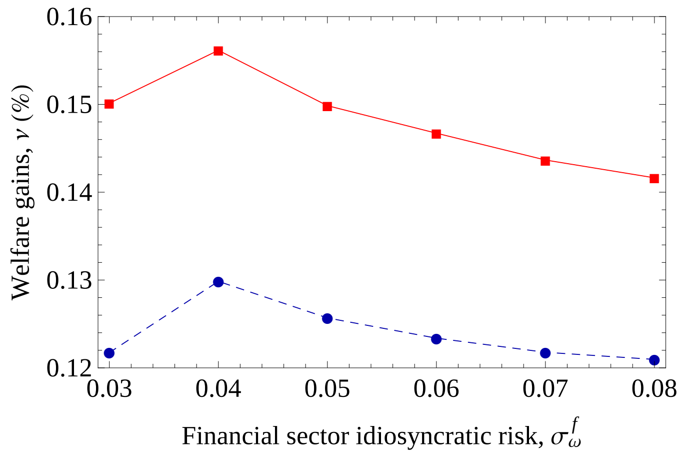

Figure 10: Welfare gains from recapitalization and idiosyncratic risk
Note: Dashed and solid lines denotes respectively the gains from "introducing" and "having" recapitalization policies as a function of the idiosyncratic risk in the financial sector

To shed light on this issue, Figure 10 shows the welfare gains from fully recapitalizing the financial sector with funds from households under different levels of idiosyncratic risk in the financial sector. Notice that as idiosyncratic risk decreases, the gains increase, which results from the increasing leverage in the financial sector that we described earlier. However, for further reductions in idiosyncratic risk, the gains start to decrease because financial frictions become less relevant enough to trump the increased leverage effect. Consequently, the model implies a non-monotonic relationship between the welfare gains from recapitalization and the financial sector's idiosyncratic risk.

7 Conclusion

The crisis that started in the U.S. in 2007 brought about a significant deterioration in the balance sheets of financial institutions followed by a sharp economic contraction. In response to these events, massive policy intervention was deployed to contain the real effects of the crisis, restore balance sheets, and speed up the recovery. These events have revamped significantly the interest of academic research in studying the role of the financial sector and the scope for policies to confront financial crises.

This paper contributes to the growing literature on financial crises by developing a dynamic-stochastic general equilibrium framework to assess the impact of large balance-sheet shocks and the merit of recapitalization policies. The key aspect of the model is the explicit modeling of financial frictions on both financial intermediaries and real firms. This allows us to study how the effects of a given net worth loss in the economy depend on which sector is primarily affected. Another distinctive feature is that we solve the model with global solution methods, instead of using linearization around the steady state. We can thus more confidently assess the quantitative impact of large shocks that involve dynamics substantially away from the steady state.

Calibrating the model with U.S. data, we show first that shocks that impair the balance sheets of the financial sector generate the largest contraction in output because of the high leverage in the sector. Responding to these shocks by recapitalizing the financial sector can lead to substantial welfare gains, roughly similar to those that would be obtained if business cycle fluctuations were entirely removed. The maximum welfare gains are obtained when the recapitalization is financed with funds from households, but using resources from the real sector also generates gains. If we were to introduce household borrowing, as long as the household is less leveraged than the other two sectors, as it is the case in the data, it will still be beneficial to recapitalize the financial sector with resources taken from the household. The welfare gains are higher in response to larger losses in the financial sector and can possibly increase after a reduction in the financial sector's idiosyncratic risk which increases its leverage.

In this paper, we have framed the analysis of recapitalization policies in a very general way, by simply considering the impact of redistributing net worth across sectors. Having shown that this kind of redistribution can lead to considerable welfare gains, it becomes interesting to compare in future research the effectiveness of alternative implementation options. In this regard, it is also important to consider the implications for moral hazard, since recapitalization policies that do not penalize sufficiently banks' managers and shareholders can lead to excessive risk taking. Finally, the modeling framework developed in the paper can also be used to analyze the effects of macroprudential policies that aim to contain leverage across the various sectors of the economy.

References

Arellano, Christina, Yan Bai, and Patrick Kehoe. 2011. "Financial Markets and Fluctuations in Uncertainty." *Unpublished Paper.*

Bernanke, Ben, Mark Gertler, and Simon Gilchrist. 1999. "The Financial Accelerator in a Quantitative Business Cycle Framework." *Handbook of Macroeconomics*, 1: 1341–1393.

Bloom, Nicholas, Max Floetotto, and Nir Jaimovich. 2011. "Really Uncertain Business Cycles." *Unpublished Paper.*

Brunnermeier, Markus K., and Yuliy Sannikov. 2010. "A Macroeconomic Model with a Financial Sector." *Working Paper.*

Carlstrom, Charles T., and Timothy S. Fuerst. 1997. "Agency Costs, Net Worth, and Business Fluctuations: A Computable General Equilibrium Analysis." *The American Economic Review*, 87(5): 893–910.

Carroll, Christopher D. 2006. "The Method of Endogenous Gridpoints for Solving Dynamic Stochastic Optimization Problems." *Economics Letters*, 91(3): 312–20.

Chen, Nan-Kuang. 2001. "Bank Net Worth, Asset Prices and Economic Activity." *Journal of Monetary Economics*, 48: 415–436.

Christiano, Lawrence, Roberto Motto, and Massimo Rostagno. 2009. "Financial Factors in Economic Fluctuations." *Working Paper.*

Cúrdia, Vasco, and Michael Woodford. 2009. "Credit frictions and optimal monetary policy." Bank for International Settlements BIS Working Papers 278.

Del Negro, Marco, Gauti Eggertsson, Nubuhiro Kiyotaki, and Andrea Ferrero. 2011. "The Great Escape? A Quantitative Evaluation of the Fed's Non-Standard Policies." *Working Paper.*

Gale, Douglas, and Martin Hellwig. 1985. "Incentive-Compatible Debt Contracts: The One-Period Problem." *The Review of Economic Studies*, 52(4): 647–663.

Gertler, Mark, and Nobuhiro Kiyotaki. 2009. "Financial Intermediation and Credit Policy in Business Cycle Analysis." *Handbook of Monetary Economics*, 3.

Gertler, Mark, and Peter Karadi. 2010. "A Model of Unconventional Monetary Policy." *Journal of Monetary Economics*, 58(1): 17–34.

Gertler, Mark, Nobuhiro Kiyotaki, and Albert Queralto. 2011. "Financial Crises, Bank Risk Exposure and Government Financial Policy." *Working Paper.*

Giannetti, Mariassunta, and Andrei Simonov. 2011. "On the Real Effects of Bank Bailouts: Micro-Evidence from Japan." *American Economic Journal: Macro (forthcoming).*

Gilchrist, Simon, Jae W. Sim, and Egon Zakrajšek. 2010. "Uncertainty, Financial Frictions, and Investment Dynamics." *Working Paper.*

Gourio, François. 2012. "Disaster Risk and Business Cycles." *American Economic Review (forthcoming).*

Hirakata, Naohisa, Nao Sudo, and Kozo Ueda. 2011. "Capital Injection, Monetary Policy, and Financial Accelerators." *IMES Discussion Paper No. 2011-E-10.*

Holmstrom, Bengt, and Jean Tirole. 1997. "Financial Intermediation, Loanable Funds, and the Real Sector." *Quarterly Journal of Economics*, 112(3): 663–691.

Iacoviello, Matteo. 2011. "Financial Business Cycles." *Boston College mimeo.*

Kiyotaki, Nobuhiro, and John Moore. 1997. "Credit Cycles." *Journal of Political Economy*, 105(2): 211–248.

Kollmann, Robert, Werner Roeger, and Jan in't Veld. 2012. "Fiscal Policy in a Financial Crisis: Standard Policy vs. Bank Rescue Measures." *American Economic Review Papers and Proceedings (forthcoming).*

Laeven, Luc, and Fabian Valencia. 2012*a*. "Real Effects of Financial Sector Interventions During Crises." *Journal of Money, Credit, and Banking (forthcoming).*

Laeven, Luc, and Fabian Valencia. 2012*b*. "Systemic Banking Crises: an Update." *International Monetary Fund working paper 12/163.*

Lucas, Robert E., Jr. 1987. *Models of Business Cycles.* Basil Blackwell, New York.

Meh, Césaire A., and Kevin Moran. 2010. "The Role of Bank Capital in the Propagation of Shocks." *Journal of Economic Dynamics & Control*, 34: 555–576.

Quadrini, Vincenzo, and Urban Jermann. 2011. "Macroeconomic Effects of Financial Shocks." *American Economic Review.* Forthcoming.

Townsend, Robert M. 1979. "Optimal Contracts and Competitive Markets with Costly State Verification." *Journal of Economic Theory*, 21(2): 265–935.

Williamson, Stephen. 1987. "Costly Monitoring, Loan Contracts, and Equilibrium Credit Rationing." *The Quarterly Journal of Economics*, 102(1): 135–145.