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A model of unconventional monetary policy

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ABSTRACT

We develop a quantitative monetary DSGE model with financial intermediaries that face endogenously determined balance sheet constraints. We then use the model to evaluate the effects of the central bank using unconventional monetary policy to combat a simulated financial crisis. We interpret unconventional monetary policy as expanding central bank credit intermediation to offset a disruption of private financial intermediation. Within our framework the central bank is less efficient than private intermediaries at making loans but it has the advantage of being able to elastically obtain funds by issuing riskless government debt. Unlike private intermediaries, it is not balance sheet constrained. During a crisis, the balance sheet constraints on private intermediaries tighten, raising the net benefits from central bank intermediation. These benefits may be substantial even if the zero lower bound constraint on the nominal interest rate is not binding. In the event this constraint is binding, though, these net benefits may be significantly enhanced.

1. Introduction

Over most of the post-war period the Federal Reserve conducted monetary policy by manipulating the Federal Funds rate in order to affect market interest rates. It largely avoided lending directly in private credit markets.

After the onset of the sub-prime crisis in August 2007, the situation changed dramatically. To address the deterioration in both financial and real activity, the Fed directly injected credit into private markets. It began in the fall of 2007 by expanding the ease at which financial institutions could obtain discount window credit and by exchanging government debt for high grade private debt. The most dramatic interventions came following the collapse of the shadow banking system that followed the Lehman Brothers failure. At this time the Fed began directly lending in high grade credit markets. It provided backstop funding to help revive the commercial paper market. It also intervened heavily in mortgage markets by directly purchasing agency debt and mortgage-backed securities. There is some evidence to suggest that these policies have been effective in reducing credit costs. Commercial paper rates relative to similar maturity Treasury Bills fell dramatically after the introduction of backstop facilities in this market. Credit spreads for agency debt and mortgage-backed securities also fell in conjunction with the introduction of the direct lending facilities.

The Fed's balance sheet provides the most concrete measure of its credit market intervention: since August 2007 the quantity of assets it has held has increased from about 800 billion to over two trillion, with most of the increase coming after the Lehman collapse. Most of the increase in assets the central absorbed were financial instruments previously held by the shadow banks. Further, it financed its balance sheet expansion largely with interest bearing reserves, which are in effect overnight government debt. Thus, over this period the Fed has attempted to offset the disruption of a considerable

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fraction of private financial intermediation by expanding central bank intermediation. To do so, it has exploited its ability to raise funds quickly and cheaply by issuing (in effect) riskless government debt. Overall, the Fed's unconventional balance sheet operations appeared to provide a way for it to stimulate the economy even after the Federal Funds reached the zero lower bound.

At the same time, operational models of monetary policy have not kept pace with the dramatic changes in actual practice. There is of course a lengthy contemporary literature on quantitative modeling of conventional monetary policy, beginning with Christiano et al. (2005) and Smets and Wouters (2007). The baseline versions of these models, however, assume frictionless financial markets. They are thus unable to capture financial market disruptions that could motivate the kind of central bank interventions in loan markets that are currently in play. Similarly, models which do incorporate financial market frictions, such as Bernanke et al. (1999) have not yet explicitly considered direct central bank intermediation as a tool of monetary policy. Work that has tried to capture this phenomenon has been mainly qualitative as opposed to quantitative (e.g. Kiyotaki and Moore, 2008; Adrian and Shin, 2009). Accordingly, the objective of this paper is to try to fill in this gap in the literature: the specific goal is to develop a quantitative macroeconomic model where it is possible to analyze the effects of unconventional monetary policy in the same general manner that existing frameworks are able to study conventional monetary policy.

To be clear, we do not attempt to explicitly model the sub-prime crisis. However, we do try to capture the key elements relevant to analyzing the Fed's credit market interventions. In particular, the current crisis has featured a sharp deterioration in the balance sheets of many key financial intermediaries. As many observers argue, the deterioration in the financial positions of these institutions has had the effect of disrupting the flow of funds between lenders and borrowers. Symptomatic of this disruption has been a sharp rise in various key credit spreads as well as a significant tightening of lending standards. This tightening of credit, in turn, has raised the cost of borrowing and thus enhanced the downturn. The story does not end here: the contraction of the real economy has reduced asset values throughout, further weakening intermediary balance sheets, and so on. It is in this kind of climate, that the central bank has embarked on its direct lending programs.

To capture this kind of scenario, accordingly we incorporate financial intermediaries within an otherwise standard macroeconomic framework. To motivate why the condition of intermediary balance sheets influences the overall flow of credit, we introduce a simple agency problem between intermediaries and their respective depositors. The agency problem introduces endogenous constraints on intermediary leverage ratios, which have the effect of tying overall credit flows to the equity capital in the intermediary sector. As in the current crisis, a deterioration of intermediary capital will disrupt lending and borrowing in a way that raises credit costs.

To capture unconventional monetary policy in this environment, we allow the central bank to act as intermediary by borrowing funds from savers and then lending them to investors. Unlike private intermediaries, the central bank does not face constraints on its leverage ratio. There is no agency problem between the central bank and its creditors because it can commit to always honoring its debt (which as we noted earlier is effectively government debt.) Thus, in a period of financial distress that has disrupted private intermediation, the central bank can intervene to support credit flows. On the other hand, we allow for the fact that, everything else equal, public intermediation is likely to be less efficient than the private intermediation. When we use the model to evaluate these credit interventions, we take into account this trade-off.

Section 2 presents the baseline model. The framework is closely related to the financial accelerator model developed by Bernanke et al. (BGG, 1999).[2] That approach emphasized how balance sheet constraints could limit the ability of non-financial firms to obtain investment funds. Firms effectively borrowed directly from households and financial intermediaries were simply a veil. Here, as we discussed, financial intermediaries may be subject to endogenously determined balance sheet constraints. In addition, we allow for the central bank to lend directly to private credit markets.

Another difference from BGG is that, we use as a baseline framework the conventional monetary business cycle framework developed by Christiano et al. (CEE, 2005a), Smets and Wouters (SW, 2007) and others. We adopt this approach because this framework has proven to have reasonable empirical properties. Here we use it to study not only conventional interest policy but also unconventional credit market interventions by the central bank.

Section 3 presents a quantitative analysis of the model. We illustrate how financial factors may amplify and propagate some conventional disturbances. We also consider a disturbance to the underlying quality of intermediary assets (a "valuation shock") and then show how this kind of disturbance could create a contraction in real activity that mirrors some of the basic features of the current crisis. As we show, either an actual decline in asset quality or the expectation (e.g. "news") of a future decline can trigger a crisis. We then illustrate the extent to which central bank credit interventions could moderate the downturn. Finally, we show the stabilization benefits from credit policy are magnified if the zero lower bound on nominal interest rates is binding.

In Section 4, we undertake a normative analysis of credit policy. We first solve for the optimal central bank credit intervention in crisis scenario considered in Section 3. We do so under different assumptions about the efficiency costs of central bank intermediation. We then compute for each case the net welfare gains from the optimal credit market

[2] The theory underlying the financial accelerator was developed in Bernanke and Gertler (1989). For quantitative frameworks, in addition to BGG, see Carlstrom and Fuerst (1997), Iacovello (2005), Goodfriend and McCallum (2007), Gilchrist et al. (2009), Jermann and Quadrini (2010), Mendoza (2010) and Christiano et al. (2010). As an example of recent theory, see Brunnermeier and Sannikov (2010).

intervention. We find that as long as the efficiency costs are quite modest, the gains may be quite significant. As we discuss, this finding suggests a formal way to think about the central bank's choice between direct credit interventions versus alternatives such as equity injections to financial intermediaries. Within our baseline model the two policies are equivalent if we abstract from the issue of efficiency costs. For certain types of lending, e.g. securitized high grade assets such as mortgage-backed securities, the costs of central bank intermediation might be relatively low. In this case, direct central bank intermediation may be justified. In other cases, e.g. C&I loans that requires constant monitoring of borrowers, central bank intermediation may be highly inefficient. In this instance, capital injections may be the preferred route. Concluding remarks are in Section 5.

2. The baseline model

The core framework is the monetary DSGE model with nominal rigidities developed by CEE and SW. To this, we add financial intermediaries that transfer funds between households and non-financial firms. An agency problem constrains the ability of financial intermediaries to obtain funds from households. We also include a disturbance to the quality of capital. Absent financial frictions, this shock introduces only a modest decline in output, as the economy works to replenish the effective capital stock. With frictions in the intermediation process, however, the shock creates a significant capital loss in the financial sector, which in turn induces tightening of credit and a significant downturn. As we show, it is in this kind of environment that there is a potential role for central bank credit interventions.

There are five types of agents in the model: households, financial intermediaries, non-financial goods producers, capital producers, and monopolistically competitive retailers. The latter are in the model only to introduce nominal price rigidities. In addition, there is a central bank that conducts both conventional and unconventional monetary policy. Without financial intermediaries the model is isomorphic to CEE and SW. As we show, though, the addition of financial intermediaries adds only a modest degree of complexity. It has, however, a substantial effect on model dynamics and associated policy implications.

We now proceed to characterize the basic ingredients of the model.

2.1. Households

There is a continuum of identical households of measure unity. Each household consumes, saves and supplies labor. Households save by lending funds to competitive financial intermediaries and possibly also by lending funds to the government.

Within each household there are two types of members: workers and bankers. Workers supply labor and return the wages they earn to the household. Each banker manages a financial intermediary and similarly transfers any earnings back to the household. The household thus effectively owns the intermediaries that its bankers manage. The deposits it holds, however, are in intermediaries that is does not own. Finally, within the family there is perfect consumption insurance. As we make clear in the next section, this simple form of heterogeneity within the family allows us to introduce financial intermediation in a meaningful way within an otherwise representative agent framework.

At any moment in time the fraction $1-f$ of the household members are workers and the fraction f are bankers. Over time an individual can switch between the two occupations. In particular, a banker this period stays banker next period with probability θ, which is independent of history (i.e., of how long the person has been a banker.) The average survival time for a banker in any given period is thus $1/(1-\theta)$. As will become clear, we introduce a finite horizon for bankers to insure that over time they do not reach the point where they can fund all investments from their own capital. Thus every period $(1-\theta)f$ bankers exit and become workers. A similar number of workers randomly become bankers, keeping the relative proportion of each type fixed. Bankers who exit give their retained earnings to their respective household. The household, though, provides its new bankers with some start up funds, as we describe in the next sub-section.

Let C_t be consumption and L_t family labor supply. Then households preferences are given by

$$\max E_t \sum_{i=0}^{\infty} \beta^i \left[\ln(C_{t+i} - hC_{t+i-1}) - \frac{\chi}{1+\varphi} L_{t+i}^{1+\varphi} \right] \tag{1}$$

with $0<\beta<1$, $0<h<1$ and $\chi,\varphi>0$. As in CEE and SW we allow for habit formation to capture consumption dynamics. As in Woodford (2003), we consider the limit of the economy as it become cashless, and thus ignore the convenience yield to the household from real money balances.

Both intermediary deposits and government debt are one period real bonds that pay the gross real return R_t from $t-1$ to t. In the equilibrium we consider, the instruments are both riskless and are thus perfect substitutes. Thus, we impose this condition from the outset. Thus let B_{t+1} be the total quantity of short term debt the household acquires, W_t, be the real wage, Π_t net payouts to the household from ownership of both non-financial and financial firms and, T_t lump sum taxes. Then the household budget constraint is given by

$$C_t = W_t L_t + \Pi_t + T_t + R_t B_t - B_{t+1} \tag{2}$$

Note that Π_t is net the transfer the household gives to its members that enter banking at t. Finally, as will be clear later, it will not matter in our model whether households hold government debt directly or do so indirectly via financial intermediaries (who in turn issue deposits to households.)

Let ϱ_t denote the marginal utility of consumption. Then the household's first order conditions for labor supply and consumption/saving are standard:

$$\varrho_t W_t = \chi L_t^{\varphi} \tag{3}$$

with

$$\varrho_t = (C_t - hC_{t-1})^{-1} - \beta h E_t (C_{t+1} - hC_t)^{-1}$$

and

$$E_t \beta \Lambda_{t,t+1} R_{t+1} = 1 \tag{4}$$

with

$$\Lambda_{t,t+1} \equiv \frac{\varrho_{t+1}}{\varrho_t}$$

2.2. Financial intermediaries

Financial intermediaries lend funds obtained from households to non-financial firms. In addition to acting as specialists that assist in channeling funds from savers to investors, they engage in maturity transformation. They hold long term assets and fund these assets with short term liabilities (beyond their own equity capital).[3] In addition, financial intermediaries in this model are meant to capture the entire banking sector, i.e., investment banks as well as commercial banks.

Let N_{jt} be the amount of wealth – or net worth – that a banker/intermediary j has at the end of period t; B_{jt+1} the deposits the intermediary obtains from households, S_{jt} the quantity of financial claims on non-financial firms that the intermediary holds and Q_t the relative price of each claim. The intermediary balance sheet is then given by

$$Q_t S_{jt} = N_{jt} + B_{jt+1} \tag{5}$$

For the time being, we ignore the possibility of the central bank supplying funds to the intermediary.

As we noted earlier, household deposits with the intermediary at time t, pay the non-contingent real gross return R_{t+1} at $t+1$. Thus B_{jt+1} may be thought of as the intermediary's debt and N_{jt} as its equity capital. Intermediary assets earn the stochastic return R_{kt+1} over this period. Both R_{kt+1} and R_{t+1} will be determined endogenously.

Over time, the banker's equity capital evolves as the difference between earnings on assets and interest payments on liabilities:

$$N_{jt+1} = R_{kt+1} Q_t S_{jt} - R_{t+1} B_{jt+1} \tag{6}$$

$$= (R_{kt+1} - R_{t+1}) Q_t S_{jt} + R_{t+1} N_{jt} \tag{7}$$

Any growth in equity above the riskless return depends on the premium $R_{kt+1} - R_{t+1}$ the banker earns on his assets, as well as his total quantity of assets, $Q_t S_{jt}$.

Let $\beta^i \Lambda_{t,t+i}$ be the stochastic discount the banker at t applies to earnings at $t+i$. Since the banker will not fund assets with a discounted return less than the discounted cost of borrowing, for the intermediary to operate in period i the following inequality must apply:

$$E_t \beta^i \Lambda_{t,t+1+i} (R_{kt+1+i} - R_{t+1+i}) \geq 0, \quad i \geq 0$$

With perfect capital markets, the relation always holds with equality: the risk adjusted premium is zero. With imperfect capital markets, however, the premium may be positive due to limits on the intermediary's ability to obtain funds.[4]

So long as the intermediary can earn a risk adjusted return that is greater than or equal to the return the household can earn on its deposits, it pays for the banker to keep building assets until exiting the industry. Accordingly, the banker's objective is to maximize expected terminal wealth, given by

$$V_{jt} = \max E_t \sum_{i=0}^{\infty} (1-\theta)\theta^i \beta^{i+1} \Lambda_{t,t+1+i} (N_{jt+1+i}) = \max E_t \sum_{i=0}^{\infty} (1-\theta)\theta^i \beta^{i+1} \Lambda_{t,t+1+i} [(R_{kt+1+i} - R_{t+1+i}) Q_{t+i} S_{jt+i} + R_{t+1+i} N_{jt+i}] \tag{8}$$

[3] In Gertler and Kiyotaki (2010), we consider a generalization of this framework that has banks manage liquidity risks (stemming from idiosyncratic shocks to firm investment opportunities) via an interbank market. In this setup, financial frictions may also affect the functioning of the interbank market.

[4] See Justiniano et al. (2010a, 2010b) for evidence that this premium is highly countercyclical and in fact opened up widely during the 2007–2009 recession.

To the extent the discounted risk adjusted premium in any period, $\beta^i \Lambda_{t,t+i}(R_{kt+1+i}-R_{t+1+i})$, is positive, the intermediary will want to expand its assets indefinitely by borrowing additional funds from households. To motivate a limit on its ability to do so, we introduce the following moral hazard/costly enforcement problem: at the beginning of the period the banker can choose to divert the fraction λ of available funds from the project and instead transfer them back to the household of which he or she is a member.[5] The cost to the banker is that the depositors can force the intermediary into bankruptcy and recover the remaining fraction $1-\lambda$ of assets. However, it is too costly for the depositors to recover the fraction λ of funds that the banker diverted.

Accordingly for lenders to be willing to supply funds to the banker, the following incentive constraint must be satisfied:

$$V_{jt} \geq \lambda Q_t S_{jt} \tag{9}$$

The left side is what the banker would lose by diverting a fraction of assets. The right side is the gain from doing so.

We can express V_{jt} as follows:

$$V_{jt} = \nu_t \cdot Q_t S_{jt} + \eta_t N_{jt} \tag{10}$$

with

$$\begin{aligned} \nu_t &= E_t\{(1-\theta)\beta\Lambda_{t,t+1}(R_{kt+1}-R_{t+1}) + \beta\Lambda_{t,t+1}\theta x_{t,t+1}\nu_{t+1}\} \\ \eta_t &= E_t\{(1-\theta) + \beta\Lambda_{t,t+1}\theta z_{t,t+1}\eta_{t+1}\} \end{aligned} \tag{11}$$

where $x_{t,t+i} \equiv Q_{t+i}S_{jt+i}/Q_t S_{jt}$, is the gross growth rate in assets between t and $t+i$, and $z_{t,t+i} \equiv N_{jt+i}/N_{jt}$ is the gross growth rate of net worth. The variable ν_t has the interpretation of the expected discounted marginal gain to the banker of expanding assets $Q_t S_{jt}$ by a unit, holding net worth N_{jt} constant, and while η_t is the expected discounted value of having another unit of N_{jt}, holding S_{jt} constant. With frictionless competitive capital markets, intermediaries will expand borrowing to the point where rates of return will adjust to ensure ν_t is zero. The agency problem we have introduced, however, may place limits on this arbitrage. In particular, as we next show, when the incentive constraints is binding, the intermediary's assets are constrained by its equity capital.

Note first that we can express the incentive constraints as

$$\eta_t N_{jt} + \nu_t Q_t S_{jt} \geq \lambda Q_t S_{jt} \tag{12}$$

If this constraint binds, then the assets the banker can acquire will depend positively on his/her equity capital:

$$Q_t S_{jt} = \frac{\eta_t}{\lambda - \nu_t} N_{jt} = \phi_t N_{jt} \tag{13}$$

where ϕ_t is the ratio of privately intermediated assets to equity, which we will refer to as the (private) leverage ratio. Holding constant N_{jt}, expanding S_{jt} raises the bankers' incentive to divert funds. The constraint (13) limits the intermediaries leverage ratio to the point where the banker's incentive to cheat is exactly balanced by the cost. In this respect the agency problem leads to an endogenous capital constraint on the intermediary's ability to acquire assets.

Given $N_{jt} > 0$, the constraint binds only if $0 < \nu_t < \lambda$. In this instance, it is profitable for the banker to expand assets (since $\nu_t > 0$). Note that in this circumstance the leverage ratio that depositors will tolerate is increasing in ν_t. The larger is ν_t, the greater is the opportunity cost to the banker from being forced into bankruptcy. If ν_t increases above λ, the incentive constraint does not bind: the franchise value of the intermediary always exceed the gain from diverting funds. In the equilibrium we construct below, under reasonable parameter values the constraint always binds within a local region of the steady state.

We can now express the evolution of the banker's net worth as

$$N_{jt+1} = [(R_{kt+1}-R_{t+1})\phi_t + R_{t+1}]N_{jt} \tag{14}$$

Note that the sensitivity of N_{jt+1} to the ex post realization of the excess return $R_{kt+1}-R_{t+1}$ is increasing in the leverage ratio ϕ_t. In addition, it follows that

$$z_{t,t+1} = N_{jt+1}/N_{jt} = (R_{kt+1}-R_{t+1})\phi_t + R_{t+1}$$

$$x_{t,t+1} = Q_{t+1}S_{jt+2}/Q_t S_{t+1} = (\phi_{t+1}/\phi_t)(N_{jt+1}/N_t) = (\phi_{t+1}/\phi_t)z_{t,t+1}$$

Importantly, all the components of ϕ_t do not depend on firm-specific factors. Thus to determine total intermediary demand for assets we can sum across individual demands to obtain

$$Q_t S_t = \phi_t N_t \tag{15}$$

where S_t reflects the aggregate quantity of intermediary assets and N_t denotes aggregate intermediary capital. In the general equilibrium of our model, variation in N_t, will induce fluctuations in overall asset demand by intermediaries. Indeed, a crisis will feature a sharp contraction in N_t.

[5] One way the banker may divert assets is to pay out large bonuses and dividends to the household.

We can derive an equation of motion for N_t, by first recognizing that it is the sum of the net worth of existing banker/intermediaries, N_{et}, and the net worth of entering (or "new") bankers, N_{nt}.

$$N_t = N_{et} + N_{nt} \tag{16}$$

Since the fraction θ of bankers at $t-1$ survive until t, N_{et} is given by

$$N_{et} = \theta[(R_{kt} - R_t)\phi_{t-1} + R_t]N_{t-1} \tag{17}$$

Observe that the main source of variation in N_{et} will be fluctuations in the ex post return on assets R_{kt}. Further, the impact on N_{et} is increasing in the leverage ratio ϕ_t.

As we noted earlier, newly entering bankers receive "start up" funds from their respective households. We suppose that the startup money the household gives its new banker a transfer equal to a small fraction of the value of assets that exiting bankers had intermediated in their final operating period. The rough idea is that how much the household feels that its new bankers need to start, depends on the scale of the assets that the exiting bankers have been intermediating. Given that the exit probability is i.i.d., the total final period assets of exiting bankers at t is $(1-\theta)Q_tS_{t-1}$. Accordingly we assume that each period the household transfers the fraction $\omega/(1-\theta)$ of this value to its entering bankers. Accordingly, in the aggregate,

$$N_{nt} = \omega Q_t S_{t-1} \tag{18}$$

Combining (17) and (18) yields the following equation of motion for N_t.

$$N_t = \theta[(R_{kt} - R_t)\phi_{t-1} + R_t]N_{t-1} + \omega Q_t S_{t-1}$$

Observe that ω helps pin down the steady state leverage ratio QS/N. Indeed, in the next section we calibrate ω to match this evidence. The resulting value, as we show, is quite small.

2.3. Credit policy

In the previous section we characterized how the total value of privately intermediated assets, Q_tS_{pt}, is determined. We now suppose that the central bank is willing to facilitate lending. Let Q_tS_{gt} be the value of assets intermediated via government assistance and let Q_tS_t be the total value of intermediated assets: i.e.,

$$Q_tS_t = Q_tS_{pt} + Q_tS_{gt} \tag{19}$$

To conduct credit policy, the central bank issues government debt to households that pays the riskless rate R_{t+1} and then lends the funds to non-financial firms at the market lending rate R_{kt+1}. We suppose that government intermediation involves efficiency costs: in particular, the central bank credit involves an efficiency cost of τ per unit supplied. This deadweight loss could reflect the costs of raising funds via government debt. It might also reflect costs to the central bank of identifying preferred private sector investments. On the other hand, the government always honors its debt: thus, unlike the case with private financial institutions there is no agency conflict than inhibits the government from obtaining funds from households. Put differently, unlike private financial intermediation, government intermediation is not balance sheet constrained.[6]

An equivalent formulation of credit policy has the central bank issue government debt to financial intermediaries. Intermediaries in turn fund their government debt holdings by issuing deposits to households that are perfect substitutes. Assuming the agency problem applies only to the private assets it holds, a financial intermediary is not constrained in financing its government debt holdings. Thus, only the funding of private assets by financial institutions is balance sheet constrained. As in the baseline scenario, the central bank is able to elastically issue government debt to fund private assets. It is straightforward to show that the equilibrium conditions in the scenario are identical to those in the baseline case. (The identical intermediary balance sheet constraint on private assets holds). One virtue of this scenario is that the intermediary holdings of government debt are interpretable as interest bearing reserves.[7]

Accordingly, suppose the central bank is willing to fund the fraction ψ_t of intermediated assets: i.e.,

$$Q_tS_{gt} = \psi_t Q_t S_t \tag{20}$$

It issues government bonds B_{gt} equal to $\psi_t Q_t S_t$ to fund this activity. Its net earnings from intermediation in any period t thus equals $(R_{kt+1} - R_{t+1})B_{gt}$. These net earnings provide a source of government revenue and must be accounted for in the budget constraint, as we discuss later.

Since privately intermediated funds are constrained by intermediary net worth, we can rewrite Eq. (19) to obtain

$$Q_tS_t = \phi_t N_t + \psi_t Q_t S_t = \phi_{ct} N_t$$

[6] As Wallace (1981) originally noted, for government financial policy to matter it is important to identify what is special about government intermediation. Sargent and Wallace (1981) provide an early example of how credit policy could matter, based on a setting of limited participation in credit markets. For related analyses see Holmstrom and Tirole (1998), Curdia and Woodford (2010) and Gertler and Kiyotaki (2010).

[7] This analysis concentrates on the central bank's direct lending programs which we think were the most important dimension of their balance sheet activities. See Gertler and Kiyotaki (2010) for a formal characterization of the different types of credit market interventions that the Federal Reserve and Treasury pursued in the current crisis.

where ϕ_t is the leverage ratio for privately intermediated funds (see Eqs. (13) and (15)), and where ϕ_{ct} is the leverage ratio for total intermediated funds, public as well as well private:

$$\phi_{ct} = \frac{1}{1-\psi_t}\phi_t$$

Observe that ϕ_{ct} depends positively on the intensity of credit policy, as measured by ψ_t. Later we describe how the central might choose ψ_t to combat a financial crisis.

2.4. Intermediate goods firms

We next turn to the production and investment side of the model economy. Competitive non-financial firms produce intermediate goods that are eventually sold to retail firms. The timing is as follows: at the end of period t, an intermediate goods producer acquires capital K_{t+1} for use in production in the subsequent period. After production in period $t+1$, the firm has the option of selling the capital on the open market. There are no adjustment costs at the firm level. Thus, the firm's capital choice problem is always static, as we discuss below.

The firm finances its capital acquisition each period by obtaining funds from intermediaries. To acquire the funds to buy capital, the firm issues S_t claims equal to the number of units of capital acquired K_{t+1} and prices each claim at the price of a unit of capital Q_t. That is, Q_tK_{t+1} is the value of capital acquired and Q_tS_t is the value of claims against this capital. Then by arbitrage:

$$Q_tK_{t+1} = Q_tS_t \tag{21}$$

We assume that there are no frictions in the process of non-financial firms obtaining funding from intermediaries. The intermediary has perfect information about the firm and has no problem enforcing payoffs. This contrasts with the process of the intermediary obtaining funding from households. Thus, within our model, only intermediaries face capital constraints on obtaining funds. These constraints, however, affect the supply of funds available to non-financial firms and hence the required rate of return on capital these firms must pay.[8] Conditional on this required return, however, the financing process is frictionless for non-financial firms. The firm is thus able to offer the intermediary a perfectly state-contingent security, which is best though of as equity (or perfectly state-contingent debt.)

At each time t, the firm produces output Y_t, using capital and labor L_t, and by varying the utilization rate of capital, U_{t+1}. Let A_t denote total factor productivity and let ξ_t denote the quality of capital (so that ξ_tK_t is the effective quantity of capital at time t). Then production is given by

$$Y_t = A_t(U_t\xi_tK_t)^{\alpha}L_t^{1-\alpha} \tag{22}$$

Following Merton (1973) and others, the shock ξ_t is meant to provide a simple source of exogenous variation in the value of capital. In the context of the model, it corresponds to economic depreciation (or obsolescence) of capital. We emphasize though, that the market value of an effective unit of capital Q_t is determined endogenously as we show shortly.

Let P_{mt} be the price of intermediate goods output. Assume further that the replacement price of used capital is fixed at unity. Then at time t, the firm chooses the utilization rate and labor demand as follows:

$$P_{mt}\alpha\frac{Y_t}{U_t} = \delta'(U_t)\xi_tK_t \tag{23}$$

$$P_{mt}(1-\alpha)\frac{Y_t}{L_t} = W_t \tag{24}$$

Given that the firm earns zero profits state by state, it simply pays out the ex post return to capital to the intermediary. Accordingly R_{kt+1} is given by

$$R_{kt+1} = \frac{\left[P_{mt+1}\alpha\frac{Y_{t+1}}{\xi_{t+1}K_{t+1}} + Q_{t+1} - \delta(U_{t+1})\right]\xi_{t+1}}{Q_t} \tag{25}$$

Given that the replacement price of capital that has depreciated is unity, then the value of the capital stock that is left over is given by $(Q_{t+1}-\delta(U_{t+1}))\xi_{t+1}K_{t+1}$.[9] Observe that the valuation shock ξ_{t+1} provides a source of variation in the return to capital. Note also that the current asset price will in general depend on beliefs about the expected future path of ξ_{t+i}.

[8] Many non-financial corporations hold significant cash reserves which raises the issue of whether they can simply self-finance investment. However, the evidence suggests that these cash holdings are typically precautionary balances held by firms to meet unanticipated expenditure needs and not cash that is free to use for investment expenditures. In particular, the firms that hold cash balances as a buffer are typically those with imperfect access to credit markets, for which lines of credit are prohibitively expensive. See Acharya et al. (2010) and the references therein.

[9] As we make clear in the next sub-section, we assume that adjustment costs are on net rather than gross investment, so that the replacing worn out equipment does not involve adjustment costs.

2.5. Capital producing firms

At the end of period t, competitive capital producing firms buy capital from intermediate goods producing firms and then repair depreciated capital and build new capital. They then sell both the new and re-furbished capital. As we noted earlier, the cost of replacing worn out capital is unity. The value of a unit of new capital is Q_t. While there are no adjustment costs associated with refurbishing capital, we suppose that there are flow adjustment costs associated with producing new capital. We assume households own capital producers and are the recipients of any profits.

Let I_t be gross capital created and $I_{nt} \equiv I_t - \delta(U_t)\xi_t K_t$ be net capital created, and I_{ss} the steady state investment. Then discounted profits for a capital producer are given by

$$\max E_t \sum_{\tau=t}^{\infty} \beta^{T-t} \Lambda_{t,\tau} \left\{ (Q_\tau - 1) I_{n\tau} - f\left(\frac{I_{n\tau} + I_{ss}}{I_{n_{\tau-1}} + I_{ss}}\right)(I_{n\tau} + I_{ss}) \right\} \tag{26}$$

with

$$I_{nt} \equiv I_t - \delta(U_t)\xi_t K_t$$

where $f(1) = f'(1) = 0$ and $f''(1) > 0$, and where $\delta(U_t)\xi_t K_t$ is the quantity of capital refurbished. As in CEE, we allow for flow adjustment costs of investment, but restrict these costs to depend on the net investment flow.[10] Note that because of the flow adjustment costs, the capital producer may earn profits outside of steady state. We assume that they rebate these profits lump sum back to households. Note also that all capital producers choose the same net investment rate. (For this reason, we do not index I_{nt} by producer type.)

The first order condition for investment gives the following "Q" relation for net investment:

$$Q_t = 1 + f(\cdot) + \frac{I_{nt} + I_{ss}}{I_{nt-1} + I_{ss}} f'(\cdot) - E_t \beta \Lambda_{t,t+1} \left(\frac{I_{nt+1} + I_{ss}}{I_{nt} + I_{ss}}\right)^2 f'(\cdot) \tag{27}$$

2.6. Retail firms

Final output Y_t is a CES composite of a continuum of mass unity of differentiated retail firms, that use intermediate output as the sole input. The final output composite is given by

$$Y_t = \left[\int_0^1 Y_{ft}^{(\varepsilon-1)/\varepsilon} df \right]^{\varepsilon/(\varepsilon-1)} \tag{28}$$

where Y_{ft} is output by retailer f. From cost minimization by users of final output:

$$Y_{ft} = \left(\frac{P_{ft}}{P_t}\right)^{-\varepsilon} Y_t \tag{29}$$

$$P_t = \left[\int_0^1 P_{ft}^{1-\varepsilon} df \right]^{1/(1-\varepsilon)} \tag{30}$$

Retailers simply re-package intermediate output. It takes one unit of intermediate output to make a unit of retail output. The marginal cost is thus the relative intermediate output price P_{mt}. We introduce nominal rigidities following CEE. In particular, each period a firm is able to freely adjust its price with probability $1-\gamma$. In between these periods, the firm is able to index its price to the lagged rate of inflation. The retailers pricing problem then is to choose the optimal reset price P_t^* to solve

$$\max E_t \sum_{i=0}^{\infty} \gamma^i \beta^i \Lambda_{t,t+i} \left[\frac{P_t^*}{P_{t+i}} \prod_{k=1}^{i} (1 + \pi_{t+k-1})^{\gamma_p} - P_{mt+i} \right] Y_{ft+i} \tag{31}$$

where π_t is the rate of inflation from $t-i$ to t. The first order necessary conditions are given by E_t

$$\sum_{i=0}^{\infty} \gamma^i \beta^i \Lambda_{t,t+i} \left[\frac{P_t^*}{P_{t+i}} \prod_{k=1}^{i} (1 + \pi_{t+k-1})^{\gamma_p} - \mu P_{mt+i} \right] Y_{ft+i} = 0 \tag{32}$$

with

$$\mu = \frac{1}{1 - 1/\varepsilon}$$

From the law of large numbers, the following relation for the evolution of the price level emerges.

$$P_t = [(1-\gamma)(P_t^*)^{1-\varepsilon} + \gamma(\Pi_{t-1}^{\gamma_p} P_{t-1})^{1-\varepsilon}]^{1/(1-\varepsilon)} \tag{33}$$

[10] Adjustment costs are on net rather than gross investment to make the capital decision independent of the market price of capital.

2.7. Resource constraint and government policy

Output is divided between consumption, investment, government consumption, G_t and expenditures on government intermediation, $\tau\psi_t Q_t K_{t+1}$. We suppose further that government expenditures are exogenously fixed at the level G. The economy-wide resource constraint is thus given by

$$Y_t = C_t + I_t + f\left(\frac{I_{nt}+I_{ss}}{I_{n_{t-1}}+I_{ss}}\right)(I_{nt}+I_{ss}) + G + \tau\psi_t Q_t K_{t+1} \tag{34}$$

where capital evolves according to

$$K_{t+1} = \xi_t K_t + I_{nt} \tag{35}$$

Government expenditures, further, are financed by lump sum taxes and government intermediation:

$$G + \tau\psi_t Q_t K_{t+1} = T_t + (R_{kt} - R_t)B_{gt-1} \tag{36}$$

where government bonds, B_{gt-1}, finance total government intermediated assets, $Q_t\psi_{t-1}S_{t-1}$.

We suppose monetary policy is characterized by a simple Taylor rule with interest-rate smoothing. Let i_t be the net nominal interest rate, i the steady state nominal rate, and Y_t^* the natural (flexible price equilibrium) level of output. Then

$$i_t = (1-\rho)[i + \kappa_\pi \pi_t + \kappa_y(\log Y_t - \log Y_t^*)] + \rho i_{t-1} + \varepsilon_t \tag{37}$$

where the smoothing parameter ρ lies between zero and unity, and where ε_t is an exogenous shock to monetary policy, and where the link between nominal and real interest rates is given by the following Fisher relation

$$1 + i_t = R_{t+1}\frac{E_t P_{t+1}}{P_t} \tag{38}$$

We suppose that the interest rate rule is sufficient to characterize monetary policy in normal times. In a crisis, however, we allow for credit policy. In particular, we suppose that at the onset of a crisis, which we define loosely to mean a period where credit spreads rise sharply, the central bank injects credit in response to movements in credit spreads, according to the following feedback rule:

$$\psi_t = \psi + \nu E_t[(\log R_{kt+1} - \log R_{t+1}) - (\log R_k - \log R)] \tag{39}$$

where ψ is the steady state fraction of publicly intermediated assets and $\log R_k - \log R$ is the steady state premium. In addition, the feedback parameter is positive. According to this rule, the central bank expands credit as the spread increase relative to its steady state value.

In addition, we suppose that in a crisis the central bank abandons its proclivity to smooth interest rates. In this case it sets the smoothing parameter ρ equal to zero. By proceeding this way we believe we are capturing how the central bank behaved in practice as the crisis unfolded. Further, under smoothing, most of the effect of monetary policy works through the effect on the expected path of future short rates. It is reasonable to suppose that during the crisis the central bank perceived that its ability to manage expectations of the future had diminished, leading it to adjust the current interest rate at a faster pace.

This completes the description of the model.

3. Model analysis

3.1. Calibration

Table 1 lists the choice of parameter values for our baseline model. Overall there are 18 parameters. Fifteen are conventional. Three (λ,ξ,θ) are specific to our model.

We begin with the conventional parameters. For the discount factor β, the depreciation rate δ, the capital share α, the elasticity of substitution between goods, ε, and the government expenditure share, we choose conventional values. Also, we normalize the steady state utilization rate U at unity. We use estimates from Primiceri et al. (2006) to obtain values for most of the other conventional parameters, which include: the habit parameter h, the elasticity of marginal depreciation with respect to the utilization rate, ζ, the inverse elasticity of net investment to the price of capital η_i, the relative utility weight on labor χ, the Frisch elasticity of labor supply φ^{-1}, the price rigidity parameter, γ, and the price indexing parameter γ_p. Since the policy rule the authors estimate is somewhat non-standard, we instead use the conventional Taylor rule parameters of 1.5 for the feedback coefficient on inflation, κ_π, and 0.5 for the output gap coefficient, κ_y, along with a value of 0.8 for the smoothing parameter. For simplicity, we use minus the price markup as a proxy for the output gap.

Our choice of the financial sector parameters – the fraction of capital that can be diverted λ, the proportional transfer to entering bankers ξ, and the survival probability θ – is meant to be suggestive. We pick these parameters to hit the following three targets: a steady state interest rate spread of one hundred basis points; a steady state leverage ratio of four; and an average horizon of bankers of a decade. We base the steady state target for the spread on the pre-2007 spreads between mortgage rates and government bonds and between BAA corporate versus government bonds. The steady state

Table 1
Parameters.

Households		
β	0.990	Discount rate
h	0.815	Habit parameter
χ	3.409	Relative utility weight of labor
φ	0.276	Inverse Frisch elasticity of labor supply
Financial Intermediaries		
λ	0.381	Fraction of capital that can be diverted
ω	0.002	Proportional transfer to the entering bankers
θ	0.972	Survival rate of the bankers
Intermediate good firms		
α	0.330	Effective capital share
U	1.000	Steady state capital utilization rate
$\delta(U)$	0.025	Steady state depreciation rate
ζ	7.200	Elasticity of marginal depreciation with respect to utilization rate
Capital Producing Firms		
η_i	1.728	Inverse elasticity of net investment to the price of capital
Retail firms		
ε	4.167	Elasticity of substitution
γ	0.779	Probability of keeping prices fixed
γ_P	0.241	Measure of price indexation
Government		
κ_π	1.5	Inflation coefficient of the Taylor rule
κ_y	0.50/4	Output gap coefficient of the Taylor rule
ρ_i	0.8	Smoothing parameter of the Taylor rule
$\frac{G}{Y}$	0.200	Steady state proportion of government expenditures

leverage ratio is trickier to calibrate. For investment banks and commercial banks, which were at the center of the crisis, leverage ratios (assets to equity) were extraordinarily high: typically in the range of 25–30 for the former and 15–20 for the latter. Much of this leverage reflected housing finance. For the corporate and non-corporate business sectors this ratio is closer to two in the aggregate. Ideally one would like to extend the model to a multi-sector setting which accounts for the differences in leverage ratios. In the interest of tractability, however, we stick with our one sector setting and choose a leverage ratio of four, which roughly captures the aggregate data.[11]

3.2. Experiments

We begin with several experiments designed to illustrate how the model behaves. We then consider a "crisis" experiment that mimics some of the basic features of the current downturn. We then consider the role of central bank credit policy in moderating the crisis. Finally, we explore the implications of the zero lower bound on nominal interest rates.

Fig. 1 shows the response of the model economy to three disturbances: a technology shock, a monetary shock, and shock to intermediary net worth. In each case, the direction of the shock is set to produce a downturn. The figure then shows the responses of three key variables: output, investment and the premium. In each case the solid line shows the response of the baseline model. The dotted line gives the response of the same model, but with the financial frictions removed.

The technology shock is a negative one percent innovation in TFP, with a quarterly autoregressive factor of 0.95. The intermediary balance sheet mechanism produces a modest amplification of the decline in output in the baseline model relative to the conventional DSGE model. The amplification is mainly the product of a substantially enhanced decline in investment: on the order of 50 percent relative to the frictionless model. The enhanced response of investment in the baseline model is a product of the rise in the premium, plotted in the last panel on the right. The unanticipated decline in investment reduces asset prices, which produces a deterioration in intermediary balance sheets, pushing up the premium. The increase in the cost of capital, further reduces capital demand by non-financial firms, which enhances the downturn in investment and asset prices. In the conventional model without financial frictions, of course, the premium is fixed at zero.

[11] Note that the calibration implies that the fraction of assets the banker can divert is high, more than 30 percent. This is because the target steady state leverage ratio that helps pin down this parameter is relatively low. With modest elaborations of the model it is possible to make this value much lower. The key is to have the leverage ratio high in sectors that are investing (see Gertler and Kiyotaki, 2010).

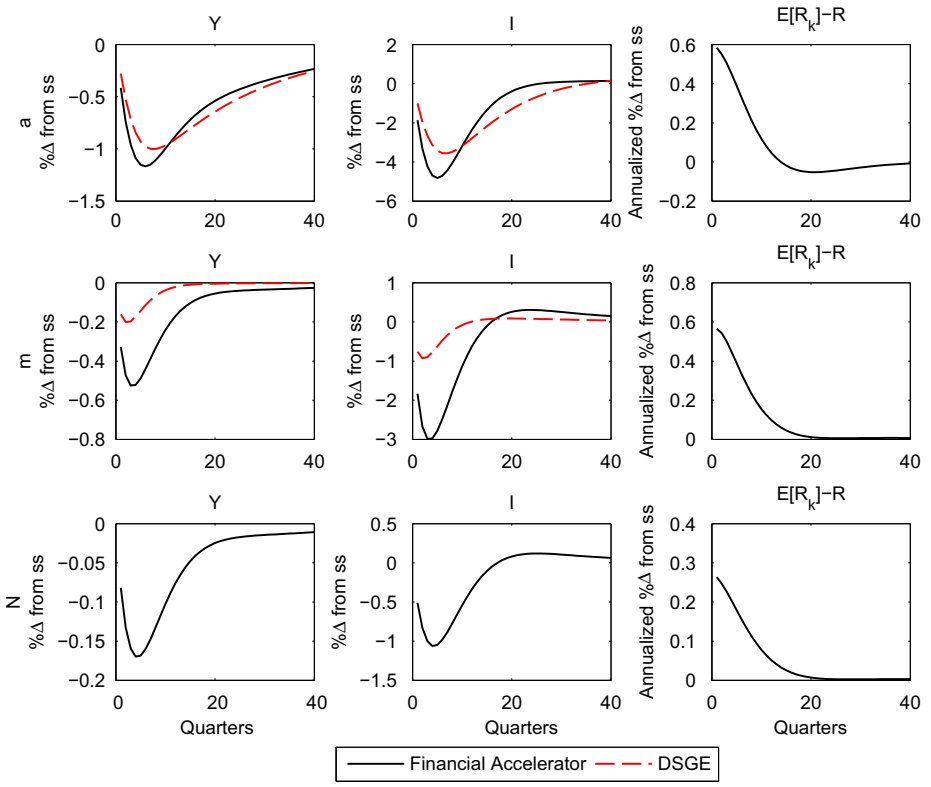

Fig. 1. Responses to Technology (a), Monetary (m) and Wealth (w) Shocks.

The monetary shock is an unanticipated 25 basis point increase in the short term interest rate. The effect on the short term interest rate persists due to interest rate smoothing by the central bank. Financial frictions lead to greater amplification relative to the case of the technology shock. This enhanced amplification is due to the fact that, everything else equal, the monetary policy shock has a relatively large effect on investment and asset prices. The latter triggers the financial accelerator mechanism.

At the core of the amplification mechanism in the first two experiments is procyclical variation in intermediary balance sheets. To illustrate this, we consider a redistribution of wealth from intermediaries to households. In particular, we suppose that intermediary net worth declines by one percent and is transferred to households. In the model with no financial frictions, this redistribution has no effect (it is just a transfer of wealth within the family). The decline in intermediary in our baseline model, however, produces a rise in the premium, leading to a subsequent decline in output and investment.

3.2.1. Crisis experiment

We now turn to the crisis experiment. The initiating disturbance is a decline in capital quality. What we are trying to capture is a shock to the quality of intermediary assets that produces an enhanced decline in the net worth of these institutions, due to their high degree of leverage. In this rough way, we capture the broad dynamics of the sub-prime crises. Note that there will be both an exogenous and endogenous component to the decline in asset values that the shock generates. The initial decline in capital reduces asset values by reducing the effective quantity of capital. There is, however, also a second round effect: due to the leverage ratio constraint, the weakening of intermediary balance sheets induces a drop in asset demand, reducing the asset price Q_t (the price per effective unit of capital) and investment. The endogenous fall in Q_t further shrinks intermediary balance sheets. The overall contraction is magnified by the degree of leverage.

It is best to think of this shock as a rare event. Conditional on occurring, however, it obeys an AR(1) process. We fix the size of the shock so that the downturn is of broadly similar magnitude to the one we have recently experienced. The initiating shock is a five percent decline in capital quality, with a quarterly autoregressive factor of 0.66. Absent any changes in investment, the shock produces a roughly 10 percent decline in the effective capital stock over a two year period. The loss in value of the housing stock relative to the total capital stock was in this neighborhood. Later we consider an "unrealized" news shock, where the private sector expects a deterioration of capital quality that is never materialized. This will allow us to make clear that the source of the financial crisis is the decline in asset values, as opposed to the physical destruction of capital.

We first consider the disturbance to the economy without credit policy and then illustrate the effects of credit policy. For the time being, we ignore the constraint imposed by the zero lower bound on the nominal interest, but then turn to this consideration.

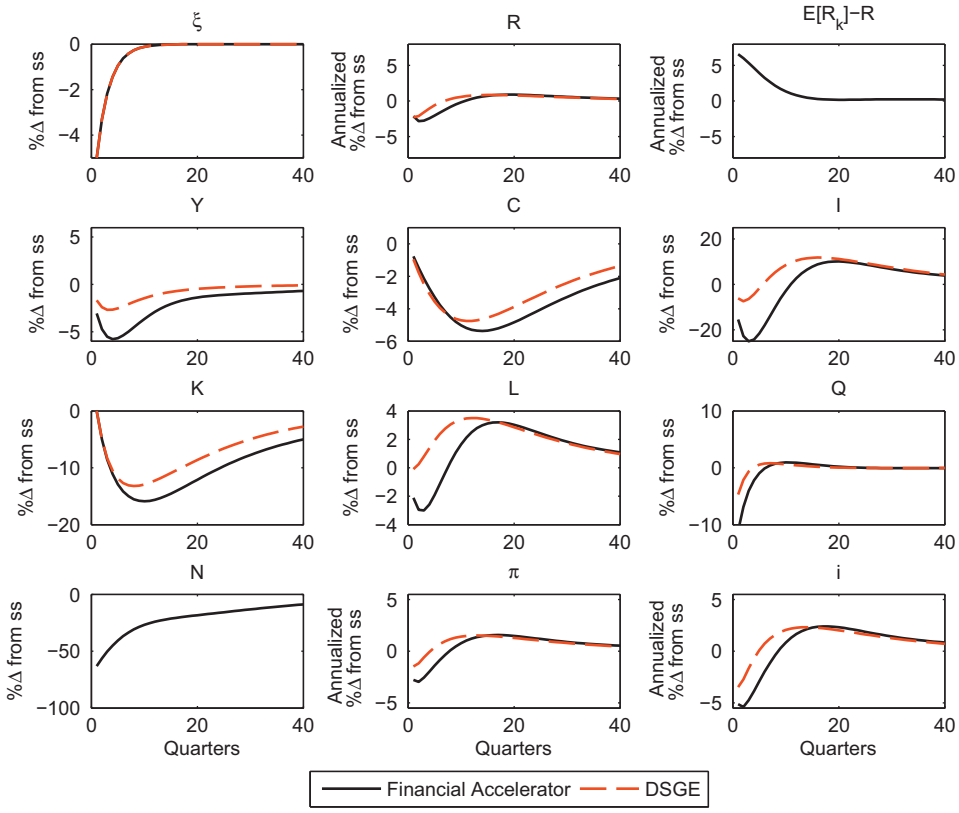

Fig. 2. Responses to a Capital Quality Shock.

As Fig. 2 illustrates, in the model without financial frictions, the shock produces only a modest decline in output. Output falls a bit initially due to the reduced effective capital stock. Because capital is below its steady state, however, investment picks up. Individuals consume less and eventually work more.

By contrast, in the model with frictions in the intermediation process, there is a sharp recession. The deterioration in intermediary asset quality induces a firesale of assets to meet balance sheet constraints. The market price of capital declines as result. Overall, on impact intermediary capital drops more than 50 percent, which is more than 10 times the initial drop in capital quality. As we noted earlier, the enhanced decline is due to the combination of the endogenous decline in Q_t and the high degree of intermediary leverage. Associated with the drop in intermediary capital, is a sharp increase in the spread between the expected return on capital and the riskless rate. Both investment and output drop as a result. Output initially falls about three percent relative to trend and then decreases to about six percent relative to trend. Though the model does not capture the details of the recession, it does produce an output decline of similar magnitude. Recovery of output to trend does not occur until roughly five years after the shock. This slow recovery is also in line with current projections. Contributing to the slow recovery is the delayed movement of intermediary capital back to trend. It is mirrored in persistently above trend movement in the spread. Note that over this period the intermediary sector is effectively deleveraging: it is building up equity relative to assets. Thus the model captures formally the informal notion of how the need for financial institutions to deleverage can slow the recovery of the economy.

3.2.2. Credit policy response

We now consider credit interventions by the central bank. Fig. 3 considers several different intervention intensities. In the first case, the feedback parameter v in the policy rule given by Eq. (39) equals 10. At this value, the credit intervention is roughly of similar magnitude to what has occurred in proactive (based on assets absorbed by the Federal Reserve on its balance sheet, as a fraction of total assets in the economy). The solid line portrays this case. In the second, the feedback parameter is raised to 100, which increases the intensity of the response, bringing it closer to the optimum (as we show in the next section). The dashed line portrays this case. Finally, for comparison, the dashed and dotted line portrays the case with no credit market intervention.

In each instance, the credit policy significantly moderates the contraction. The prime reason is that central intermediation dampens the rise in the spread, which in turn dampens the investment decline. The moderate intervention ($v = 10$) produces an increase in the central bank balance sheet equal to approximately seven percent of the value of the capital stock. This is roughly in accord with the degree of intervention that has occurred in practice. The aggressive

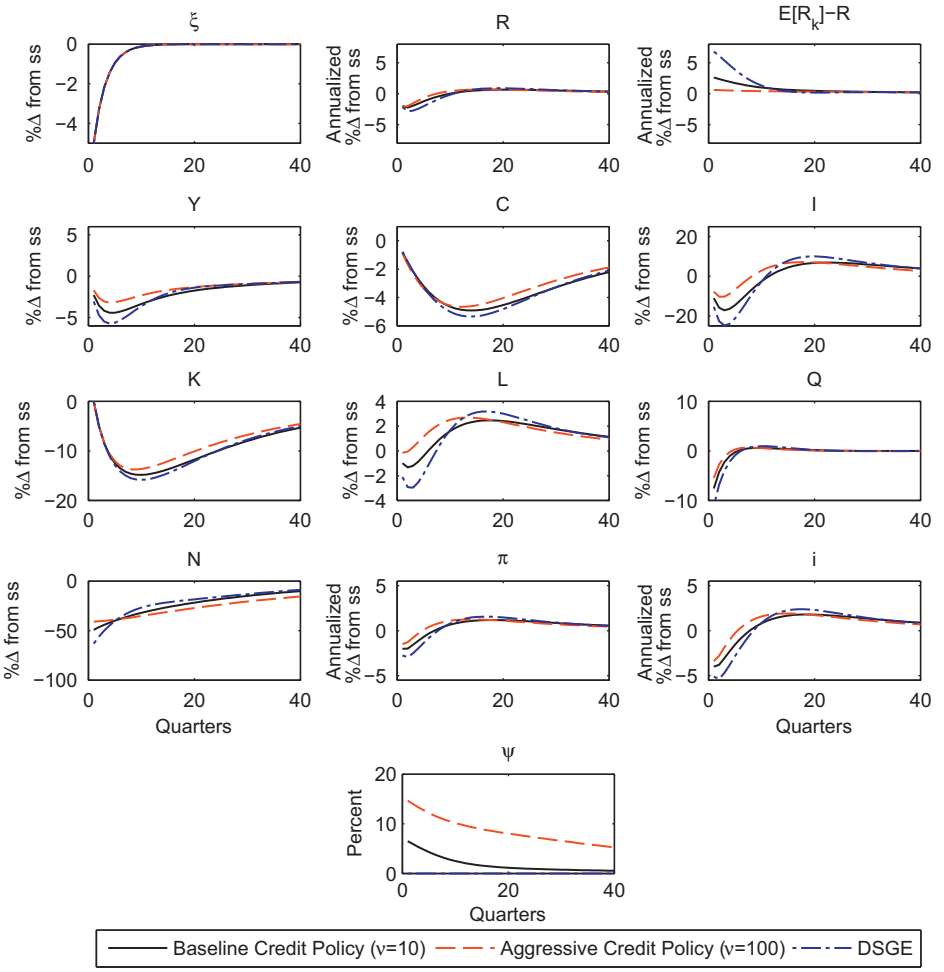

Fig. 3. Responses to a Capital Quality Shock with Credit Policy.

intervention further moderates the decline. It does so by substantially moderating the rise in the spread. Doing so, however, requires that central bank lending increase to approximately 15 percent of the capital stock.

Several other points are worth noting. First, in each instance the central bank exits from its balance sheet slowly over time. In the case of the moderate intervention the process takes roughly five years. It takes roughly three times longer in the case of the aggressive intervention. Exit is associated with private financial intermediaries re-capitalizing. As private intermediaries build up their balance sheets, they are able to absorb assets off the central bank's balance sheet.

Second, despite the large increase in the central bank's balance sheet in response to the crisis, inflation remains largely benign. The reduction in credit spreads induced by the policy provides sufficient stimulus to prevent a deflation, but not enough to ignite high inflation. Here it is important to keep in mind that the liabilities the central bank issues are government debt (financed by private assets), as opposed to unbacked high-powered money.

3.2.3. *Impact of the zero lower bound*

Next we turn to the issue of the zero lower bound on nominal interest rates. The steady state short term nominal interest rate is four hundred basis points. As Fig. 2 shows, in the baseline crisis experiment, the nominal rate drops more than 500 basis points, which clearly violates the zero lower bound on the nominal rate.[12]

In Fig. 4 we re-create the crisis experiment, this time imposing the constraint that the net nominal rate cannot fall below zero. As the figure illustrates, with this restriction, the output decline is roughly 25 percent larger than in the case without. The limit on the ability to reduce the nominal rate to offset the contraction leads to an enhanced output decline. Associated with the magnified contraction is greater financial distress, mirrored by a larger movement in the spread.

[12] For an early analysis of the implications of the zero lower bound for monetary policy, see Eggertsson and Woodford (2003).

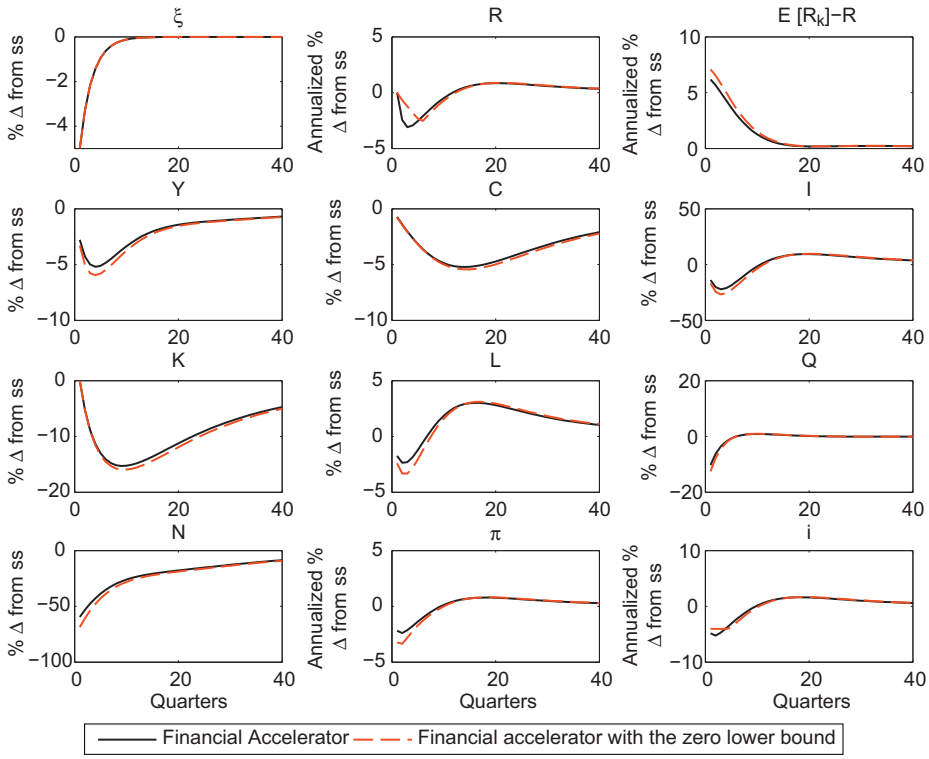

Fig. 4. Impulse responses to the capital quality shock with and without the zero lower bound (ZLB).

In Fig. 5 we re-consider the credit policy experiments, this time taking explicitly into account the zero lower bound restriction. As the figure makes clear, the relative gains from the credit policies are enhanced in this scenario. The reduced output contraction and the smaller drop in the inflation rate also shortens the period during which the interest rate policy is constrained by the zero lower bound restriction.

3.2.4. *"News" as a source of asset price variation*

We introduce the capital quality shock to provide an exogenous source of variation in asset values. Mixed in with this shock, however, is variation in the effective quantity of physical capital. While in the current crisis there was "destruction" in asset values initiated by a contraction of housing prices, there was not effective destruction of physical capital. It is beyond the scope of this paper to incorporate housing and a boom bust cycle in either house prices or asset prices more generally. However, we can do a simple experiment that separates the effect of a contraction in asset values from the effect of an effective loss of physical capital.

In particular, suppose the economy is hit by news that a capital shock is likely to hit the economy in the subsequent period with probability σ. The expected size and duration of the shock (σ times the realization of the shock in each of the subsequent periods) is the same in magnitude as the shock considered in the previous experiments. Suppose further that shock is never actually realized but that for a number of periods the private sector continues to believe it will arise with probability σ. After a point it begins to revise down the likelihood of the shock. In this case, the news will reduce asset values, but because the shock is never realized, there is not a direct impact on the effect quantity of capital. Thus, we can disentangle the "asset value" effect from the physical quantity of capital effect.

The experiment we consider proceeds as follows. We suppose the economy begins with the capital stock five percent above steady state (due perhaps to past "overoptimism" about the returns to investment). A wave of pessimism then sets in. For four straight quarters the private sector believes a capital quality shock will hit that is in expected value of the same magnitude as the autoregressive shock considered in the previous section. After the shock is not realized, the private sector then revises down the likelihood by a factor of 0.5 each period.

Fig. 6 shows the results. The news shock triggers a financial crisis and a collapse in output much like the one following the capital quality shock studied in the previous section. Asset values collapse and the spread increases, which leads to the fall in output and investment. Overall, the collapse in output is nearly double what occurs in the frictionless benchmark. In contrast to the case of the realized capital quality shock, the news shock does not directly alter the stock of capital. Thus the crisis in this case is triggered purely by a loss in asset values.

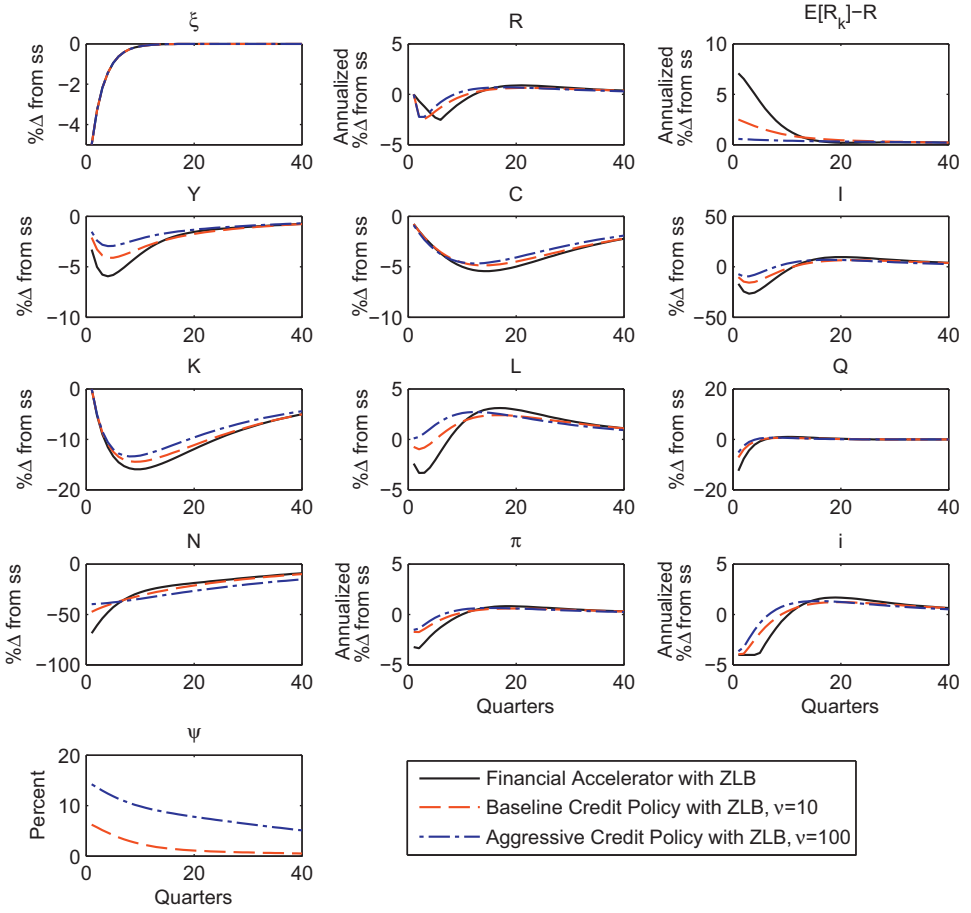

Fig. 5. Impulse responses to the capital quality shock with the zero lower bound (ZLB) with and without credit policy.

It is interesting to note that the employment drop is of the same magnitude as the output drop. As in the current crisis, labor productivity does not fall. At the same time, once it is realized that the shock will likely not happen, there is a fairly rapid bounce back of output and employment. In reality expectations were likely slower to adjust. We save a richer model of belief formation for subsequent research.

4. Optimal policy and welfare

We now consider the welfare gains from central bank credit policy and also compute the optimal degree of intervention. We take as the objective the household's utility function.

We start with the crisis scenario of the previous section. We take as given the Taylor rule (without interest rate smoothing) for setting interest rates. This rule may be thought of as describing monetary policy in normal times. We suppose that it is credit policy that adjusts to the crisis. We then ask what is the optimal choice of the feedback parameter v in the wake of the capital quality shock. In doing the experiment, we take into account the efficiency costs of central bank intermediation, as measured by the parameter τ. We consider a range of values for τ.

Following Faia and Monacelli (2007), we begin by writing the household utility function in recursive form:

$$\Omega_t = U(C_t,L_t)+\beta E_t \Omega_{t+1} \tag{40}$$

We then take a second order approximation of this function about the steady state. We next take a second order approximation of the whole model about the steady state and then use this approximation to express the objective as a second order function of the predetermined variables and shocks to the system. In doing this approximation, we take as given the policy-parameters, including the feedback credit policy parameter v. We then search numerically for the value of v that optimizes Ω_t as a response to the capital quality shock.

To compute the welfare gain from the optimal credit policy we also compute the value of Ω_t under no credit policy. We then take the difference in Ω_t in the two cases to find out how much welfare increases under the optimal credit policy. To convert to consumption equivalents, we ask how much the individuals consumption would have to increase each period in

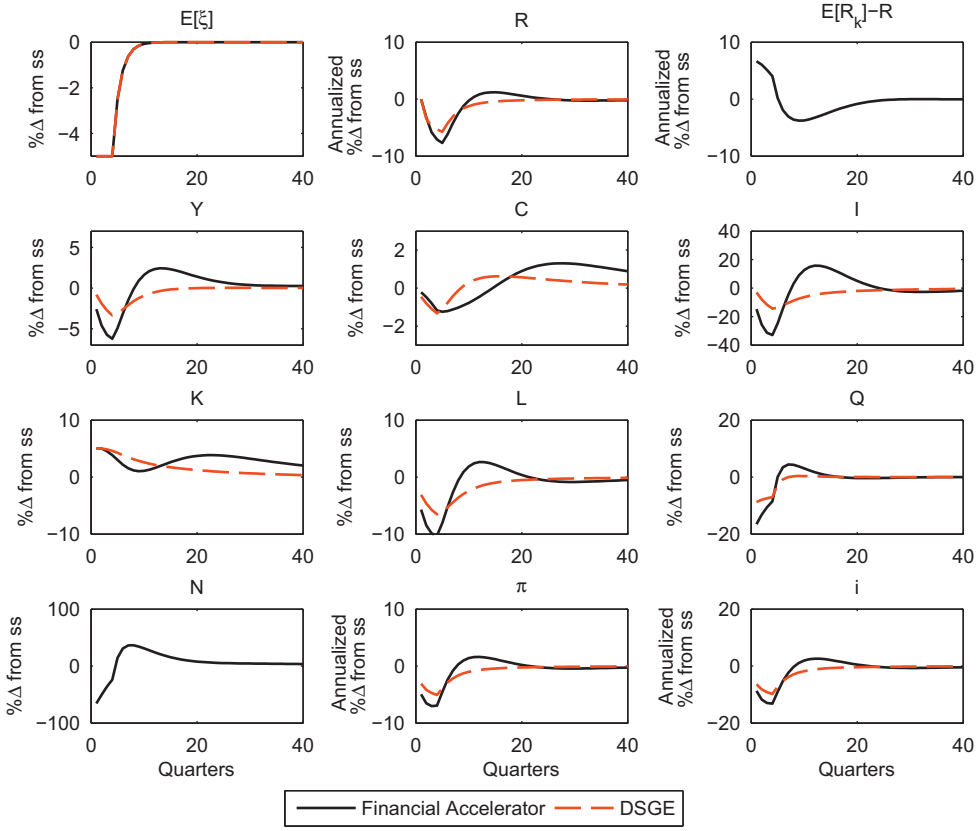

Fig. 6. Impulse responses to unrealized news shocks in a model with financial accelerator (FA) and without it (SDGE).

the no credit policy case to be indifferent with the case under the optimal credit policy. Because we are just analyzing a single crisis and not an on-going sequence, we simply calculate the present value of consumption-equivalent benefits and normalize it by one year's steady state consumption. Put differently, we suppose the economy is hit with a crisis and then ask what are the consumption-equivalent benefits from credit policy in moderating this single event. Since we are analyzing a single event, it makes sense to us to cumulate up the benefits instead of presenting them as an indefinite annuity flow, where most of the flow is received after the crisis is over.

Finally, we abstract from considerations of the zero lower bound (due to the complications from computing the second order approximation of the model in this case.) In this regard, our results understate the net benefits from credit policy.

Fig. 7 presents the results for a range of values of the efficiency cost τ. In the baseline case with no efficiency cost ($\tau = 0$), the benefit from credit policy of moderating the recession is worth roughly 8.50 percent of one years recession. At a value of 10 basis points, which is probably quite large for assets like agency backed mortgage securities and commercial paper, the efficiency gain is on the order of 7.0 percent of steady state consumption. At this value of efficiency costs, the optimal credit policy comes close to fully stabilizing the markup.

The net benefits from the credit policy reduces below 1% of yearly steady state consumption when τ reaches roughly 80 basis points. For high grade securities, however, this value for efficiency costs would be astronomical. Our analysis suggests that for reasonable values of efficiency costs (less than 10 basis points) the net gains from responding to the crisis with credit policy may be large.

5. Concluding remarks

We developed a quantitative monetary DSGE model with financial intermediaries that face endogenously determined balance sheet constraints. We then used the model to evaluate the effects of expanding central bank credit intermediation to combat a simulated financial crisis. Within our framework the central bank is less efficient than private intermediaries at making loans. Its advantage is that it can elastically obtain funds by issuing riskless government debt. Unlike private intermediaries it is not balance sheet constrained. During a crisis, the balance sheet constraints on private intermediaries tighten, raising the net benefits from central bank intermediation. We find that the welfare benefits from this policy may be substantial during a crisis if the relative efficiency costs of central bank intermediation are within reason.

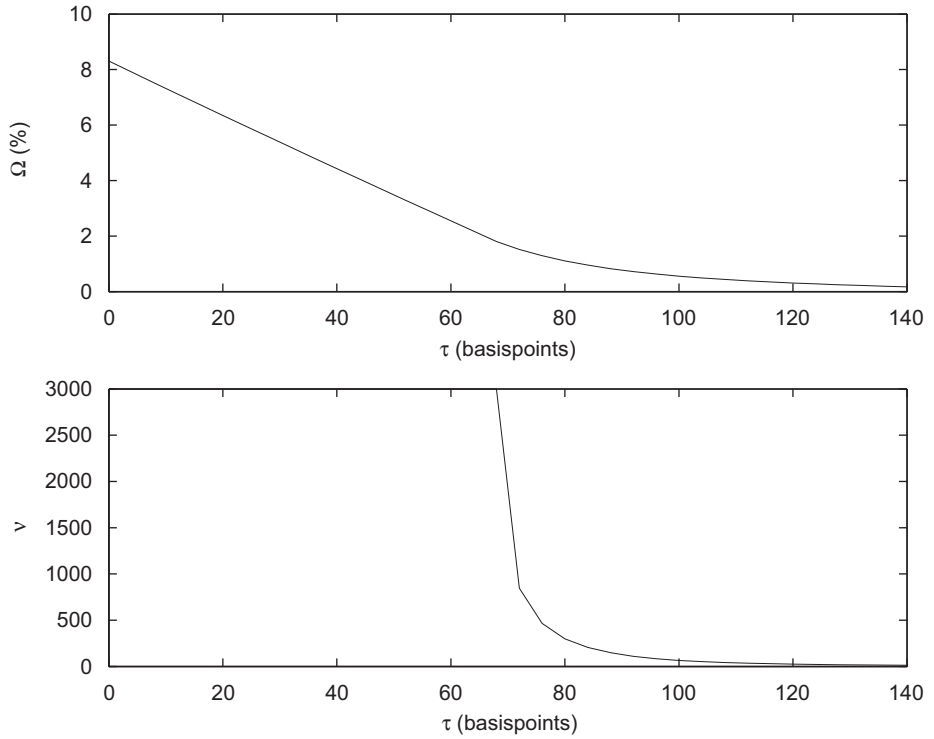

Fig. 7. One year consumption equivalent net welfare gains from optimal credit policy (Ω) and optimal credit policy coefficient (ν) as a function of efficiency costs τ.

Importantly, as we showed, in a financial crisis there are benefits credit policy even if the nominal interest has not reached the zero lower bound. In the event the zero lower bound constraint is binding, however, the net benefits from credit policy may be significantly enhanced. Conversely, as financial intermediaries re-capitalize and the economy returns to normal, the net benefits from unconventional monetary policy diminish. Given this consideration and some considerations outside the model (e.g. the "politicization" of credit allocation in normal times), we interpret our analysis as suggesting that unconventional monetary policy should be used only in crisis situations.

Our analysis focused on direct lending activities by the central bank. An alternative type of credit intervention in our model would be direct equity injections into financial intermediaries. Expanding equity in these institutions would of course expand the volume of assets that they intermediate. In our view, a key factor in choosing between equity injections and direct lending involves the relative efficiency cost of the policy action. For certain types of lending, e.g. securitized high grade assets such as mortgage-backed securities or commercial paper, the costs of central bank intermediation might be relatively low. In this case, direct central bank intermediation might be highly justified. In other cases, e.g. C&I loans that require constant monitoring of borrowers, central bank intermediation may be highly inefficient. In this instance, capital injections may be the preferred route. By expanding our model to allow for asset heterogeneity, we can address this issue.

Within our framework leverage plays a key role in the dynamics of the crisis. Leverage ratios are endogenous in the dynamics about the steady state, but the steady state leverage ratio is effectively determined exogenously. It would be interesting to endogenize the steady state leverage ratio and, in particular, try to account for what led the financial system to such a vulnerable state at the onset of the crisis. Undoubtedly, the long history of protection of large financial institutions (i.e., moral hazard stemming from too-big-to-fail) has played a role. More generally, anticipation of government credit market interventions to dampen a crisis can lead private financial institutions to take on more leverage. By extending the analysis in this direction we can explore quantitatively how moral hazard considerations might factor into the analysis of government credit policies.[13]

Along these lines, it might also be interesting to think about capital requirements in this framework, following Lorenzoni (2008). Within our framework as within his, in making capital structure decisions, individual intermediaries do not account for the spillover effects of high leverage on the volatility of asset prices.

Finally, we considered a one time crisis and evaluated the policy response. In subsequent work we plan to model the phenomenon as an infrequently occurring rare disaster, in the spirit of Barro (2009) and Gourio (2010). In this literature,

[13] See Gertler et al. (2010) for an attempt along these lines.

the disaster is taken as a purely exogenous event. Within our framework, the magnitude of the disaster is endogenous. We can, however, use the same tools as applied in this literature to compute welfare.

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Further reading

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