

The Great Escape? A Quantitative Evaluation of the Fed's Non-Standard Policies*

Marco Del Negro, Gauti Eggertsson, Andrea Ferrero, Nobuhiro Kiyotaki

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Federal Reserve Bank of New York and Princeton University

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Abstract

This paper extends the model in Kiyotaki and Moore (2008) to include nominal wage and price frictions and explicitly incorporates the zero bound on the short-term nominal interest rate. We subject this model to a shock which we argue captures the financial crisis in the US in 2008. In this framework we ask a basic question: Once interest rate cuts are no longer feasible, due to the zero bound, what are the effects of non-standard open market operations, in which the government exchanges liquid government bonds for illiquid private assets? We find that the effect of this non-standard monetary policy can be large at zero nominal interest rates. We show model simulations in which these policy interventions prevented a repeat of the Great Depression in 2008-2009.

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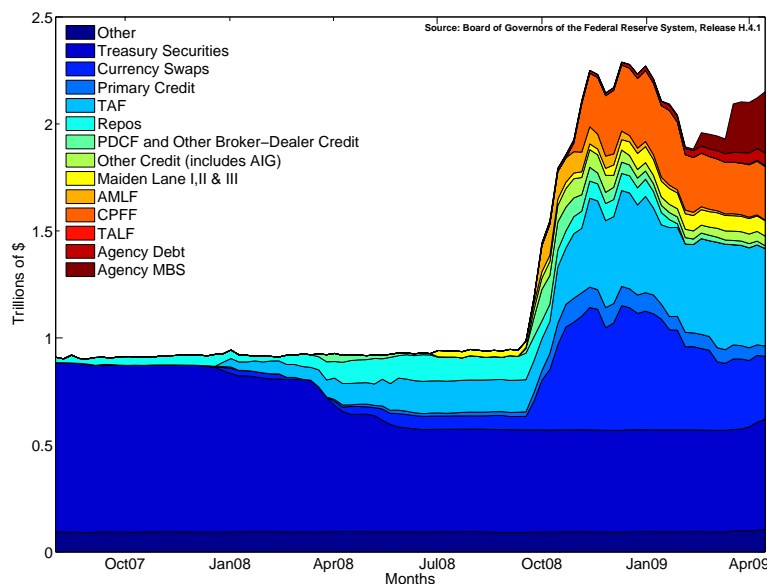


Figure 1: Asset Side of Fed's Balance Sheet

1 Introduction

In 2008, the Federal Funds rates collapsed to zero. Standard monetary policy through interest rate cuts had reached its limit. Around the same time, the Federal Reserve expanded its balance sheet by about 1 trillion dollars, or 7% of U.S. GDP (see figure 1). This expansion mostly involved the Federal Reserve exchanging government liquidity, that is money or government debt, for private assets (through direct purchases of these assets or taking them as collateral in short term loans). This was achieved through the operation of various “facilities”, such as the Term Auction Facility (TAF) or the Primary Dealer Credit Facility (PDCF). In broad terms, the operation of these facilities can be thought of as “nonstandard” open market operations, whereby the government exchanges highly liquid government liabilities for less liquid private assets. Our main result is that the quantitative effect of these operations can be very large, especially at zero interest rates.

Ever since Wallace (1982) famous irrelevance result, the benchmark for most macro-

economists, is that non-standard open market operations in private assets are irrelevant. This result was extended by Eggertsson and Woodford (2003) to show that it also applies to standard open market operations, i.e. printing money for debt, in models with nominal and monetary frictions, provided that the interest rate is zero. There is no role for “liquidity” in these models, or most other standard models with various types of frictions, such as Rotemberg and Woodford (1997), Christiano, Eichenbaum and Evans (2006), or Smets and Wouters (2006). The price of any private security – be it stock or corporate bond – depends on what it will pay out in various states of the world. The supply of these securities is irrelevant if it does not change their state contingent pay-offs. For example, in these models, the supply of Microsoft stocks traded in the private market does not matter for pricing. What matters is what they promise to pay in the future. Why should it matter if a government or a private agent holds a particular stock or security, holding constant the revenue stream that they are expected to generate? In fact, in a well known recent paper, Taylor and Williams (2008) argue that in the context of the crisis of 2008 the Federal Reserve’s facilities had no material impact. Their prior was presumably informed by modern general equilibrium theory which embeds Wallace’s irrelevance result.

In this paper we break Wallace’s irrelevance result in a straightforward fashion. We incorporate a particular form of credit frictions, proposed by Kiyotaki and Moore (2008) (henceforth, KM). Our objective is to explore what credit frictions of the form suggested by KM mean for the quantitative effect of the Federal Reserve facilities during the crisis of 2008 and 2009. The KM credit frictions are of two distinct forms. First, a firm (or a bank) that faces an investment opportunity can only borrow up to a fraction of the net present return of its investment. This is a relatively standard borrowing constraint. Second, there is a resaleability constraint in the model. A firm that faces an investment opportunity can only sell a certain fraction of its “illiquid” assets in each period. These illiquid assets correspond to equity in other firms. More generally, we interpret these illiquid assets as privately issued commercial paper, loans of banks and/or stocks, and so on. KM argue for this resaleability constraint on ground of imperfect information. We do not underpin its microfoundations in any way, but instead take it as given and

explore its quantitative implication. In contrast to private liquidity that is subject to a resaleability constraint, we follow KM and assume that government issued paper, i.e. money and bonds, are not subject to this constraint. This gives government debt and money a primary role as “liquidity” that lubricates transactions. In this world, Wallace’s irrelevance result no longer applies because privately issued paper is subject to resaleability constraints, while government paper is not. Government paper, in other words, is more “liquid”. This gives a natural story for the crisis of 2008 in the context of the model.

The shock we then consider as the source of the crisis of 2008 is a shock to the resaleability of private assets. Suddenly, the private market for credit freezes. We think of this shock as capturing central aspects of the crisis of 2008. Interestingly, for our quantitative analysis, we can calibrate this shock by matching a new observable variable that we construct from the flow of funds data and captures the “liquidity share”. In addition to using this observable to calibrate the shock in the model, we also use the 1 trillion dollar intervention to calibrate the non-standard reaction-function of the government. This allows us not only to explore the quantitative effect of the crisis shock, but also illustrate to counterfactual evolution of the economy had the Federal Reserve not intervened.

What is the quantitative effect of the “crisis” shock in the model with credit frictions? What is the consequence of non-standard policy? We explore these questions by embedding the KM credit frictions in a standard dynamic stochastic general equilibrium (DSGE) model along the lines of Christiano, Eichenbaum and Evans (2006) and Smets and Wouters (2006). This model has standard frictions, such as wage and price rigidities and aggregate capital adjustments costs. Standard monetary policy is then variations in the nominal interest rate through open market operation in government debt. Non-standard policy is open market operations in private assets that increase the overall level of liquidity in the economy.

Our first main result is that neither the financial shock nor the 1 trillion dollar intervention have a large quantitative effect in the absence of price and wage rigidities. Our second main result is that if we calibrate the other frictions in the model to values

consistent with the existing literature, and monetary policy follows a standard Taylor rule (i.e. interest rate react more than one to one to inflation), then both the financial shock and non-standard policy have a significant effect. Our third result is that once the zero bound on the short-term nominal interest rate is introduced, and in the absence of the intervention, the economy suffers a Great Depression-style collapse. In contrast, with intervention, the model exhibits similar response as now observed in the US economy. This is the “Great Escape” referred to in the title of the paper, since our numerical example illustrates that in the absence of non-standard policy the US economy would have suffered the second coming of the Great Depression. The reason why the effect of non-standard policy can be especially large at zero interest rates is similar to what is found in Christiano, Eichenbaum and Rebelo (2009) and Eggertsson (2009). They report that the “multiplier of government spending” is unusually large at zero interest rates.

This paper belongs to the strand of literature introducing financial frictions in monetary DSGE models, such as Bernanke, Gertler and Gilchrist (1999), Christiano, Motto and Rostagno (2003, 2009), Goodfriend and McCallum (2007) and Curdia and Woodford (2009*a*). Gertler and Karadi (2009), Gertler and Kiyotaki (2009) and Curdia and Woodford (2009*b*) also analyze the role of non-conventional central bank policies in the current recession.

2 The model

The model consists of six different economic actors: the entrepreneurs, the capital producers, the retail good producers, the final good producers, workers, and the government. We start with the entrepreneurs producers, as these are the least standard, and at the heart of our model. These entrepreneurs are virtually identical to those introduced by Kiyotaki and Moore (2008). The rest of the model is similar to a several recent DSGE studies.

2.1 Entrepreneurs

The economy is populated by a continuum of entrepreneurs $e \in (0, 1)$. These are agents that from now and then have an investment opportunity, and need to acquire resources to take advantage of it. The end product of the entrepreneurs is a final capital good, which they rents out to intermediate good firms for a rental rate of r_t , as we will further discuss below.

Each entrepreneur's objective is given by:

$$E_t \sum_{s=t}^{\infty} \beta^{s-t} \log(c_s(e)) \quad (1)$$

where $c_t(e)$ is the entrepreneur's consumption. Entrepreneurs have an investment opportunity with probability χ in each period – where this investment opportunity shock is i.i.d. across time and entrepreneurs – so they accumulate capital according to the law of motion:

$$k_{t+1}(e) = \begin{cases} \lambda k_t(e) + i_t(e) & \text{with probability } \chi \\ \lambda k_t(e) & \text{with probability } 1 - \chi \end{cases}, \quad (2)$$

where $0 < \lambda < 1$ is one minus the depreciation rate, and $i_t(e)$ represents investment. We assume that $\beta > \lambda$.

Financial market imperfections are modeled as constraints on the evolution of the the balance sheet of the entrepreneur. The entrepreneur's liabilities consist of $n_t^I(e)$, the equity issued by the entrepreneurs. This equity represents claims on the future stream of rental rates, and its per-unit value expressed in units of the consumption good is q_t . His assets consist of his residual claim on own capital, $k_t(e) - n_t^I(e)$, and on claims on the equity of other entrepreneurs $n_t^O(e)$. The entrepreneur's other assets consists of $m_t(e)$, which Kiyotaki and Morore refer to as “liquid assets” – a storage technology whose value in terms of output is p_t . In addition, the entrepreneur has an amount $b_t(e)$ of \$ reserves at the central bank that pay a gross nominal interest rate R_{t-1} (we adopt the same timing conventions as KM, but note that R_{t-1} is known at time $t - 1$). The value of 1 \$ of reserves in terms of output is $1/P_t$ (P_t is the usual price level). So the entr.'s balance sheet at the end of period t looks as follows:

Assets		Liabilities	
liquid assets	$p_t m_{t+1}(e)$	own equity issued	$q_t n_{t+1}^I(e)$
reserves	$b_{t+1}(e)/P_t$		
equity of other entrepreneurs	$q_t n_{t+1}^O(e)$		
capital stock	$q_t k_{t+1}(e)$	net worth	$q_t n_{t+1}(e)$ $+ p_t m_{t+1}(e) + b_{t+1}(e)/P_t$

where $n_t(e) \equiv n_t^O(e) + (k_t(e) - n_t^I(e))$.

The constraints on the evolution of the the entrepreneur's balance sheet are as follows: The entrepreneur's *Borrowing Constraint (BC)* implies that the entrepreneur can issue new equity only up to a fraction θ of the new equity $i_t(e)$ in order to finance investment $i_t(e)$.

The *Resaleability Constraint on "own" equity (RCi)* : In any given period the entr. can sell only a fraction ϕ_t^I of his equity holdings $k_t(e) - n_t^I(e)$. These two constraints together imply that the evolution of $n_t^I(e)$ is subject to the following inequality:

$$n_{t+1}^I(e) - \lambda n_t^I(e) \leq \underbrace{\phi_t^I \lambda (k_t(e) - n_t^I(e))}_{\text{RCi}} + \underbrace{\theta_t i_t(e)}_{\text{BC}}. \quad (3)$$

Resaleability Constraint on "other" equity (RCo) : The entrepreneur can sell only a fraction ϕ_t^O of his equity stake in other entrepreneurs $n_t^O(e)$:

$$-(n_{t+1}^O(e) - \lambda n_t^O(e)) \leq \phi_t^O \lambda n_t^O(e). \quad (4)$$

Assume that $\phi_t^I = \phi_t^O = \phi_t$ and add (3) and (4) together to obtain:

$$n_{t+1}(e) \geq (1 - \phi_t) \lambda n_t(e) + (1 - \theta_t) i_t(e). \quad (5)$$

In addition, the entrepreneur cannot hold negative liquid assets or reserves :

$$m_{t+1}(e) \geq 0, \quad (6)$$

$$b_{t+1}(e) \geq 0. \quad (7)$$

The entrepreneur's intertemporal budget constraint (flow of funds) is given by:

$$c_t(e) + p_t^I i_t(e) + q_t(n_{t+1}(e) - \lambda n_t(e) - i_t(e)) + p_t(m_{t+1}(e) - m_t(e)) + \frac{b_{t+1}(e) - R_{t-1}b_t(e)}{P_t} \leq r_t n_t(e), \quad (8)$$

where p_t^I is the price of investment in terms of general output, and where we used the law of motion of capital (2) and the definition of $n_t(e)$.

The problem of the entrepreneur is to maximize (1) subject to (2), (5), (7), (6), and (8) by choice of $\{n_{t+1}(e), b_{t+1}(e), m_{t+1}(e), i_t(e), c_t(e)\}$ taking the path for $\{r_t, q_t, p_t, p_t^I, R_t, P_t\}$ as exogenously given.

2.2 Capital goods producers

There are competitive capital producers that transform the consumption good into a raw capital good that the entrepreneurs buy for their investment. The objective of the capital producers is to maximize profits that are given by

$$C(I_t) = p_t^I I_t - I_t [1 + S(\frac{I_t}{I_*})]. \quad (9)$$

The capital producers are perfectly competitive so that they take p_t^I as given. The adjustment cost function depends on steady state aggregate investment I^* and we assume that $S(1) = S'(1) = 0$ and $S''(1) > 0$.

Capital producers problem: The problem of the capital producer is to maximize (9) by choice of I_t taking p_t^I as given.

2.3 Final good producers

There are two kind of good producers, the intermediate producers and the final good producers. The intermediate goods producers have market power, while the final producers do not. The final good y_t is a composite made of a continuum of intermediate goods:

$$y_t = \left[\int_0^1 y_t(i)^{\frac{1}{1+\lambda_f}} di \right]^{1+\lambda_f} \quad (10)$$

but we describe how each $y_t(i)$ of the intermediate good is produced in the next section. The final goods producers buy the intermediate goods on the market at a price $p_t(i)$, package y_t according to (10) and resell it to consumers. These firms maximize profits in a perfectly competitive environment. Their problem is:

$$\begin{aligned} \max_{y_t, y_t(i)} \quad & y_t - \int_0^1 p_t(i) y_t(i) di \\ \text{s.t. } \quad & y_t = \left[\int_0^1 y_t(i)^{\frac{1}{1+\lambda_f}} di \right]^{1+\lambda_f}, \end{aligned} \quad (11)$$

Final good producers problem: The problem of the final producer is to maximize (11) by choice of $y_t(i)$ taking $p_t(i)$ as given.

2.4 Intermediate producers

The maximization problem of the final goods producers in the last subsection gives rise to a demand function for the intermediate good given by

$$y_t(i) = \left(\frac{p_t(i)}{P_t} \right)^{-\frac{1+\lambda_f}{\lambda_f}} y_t \quad (12)$$

where

$$P_t = \left[\int_0^1 p_t(i)^{\frac{1}{\lambda_f}} di \right]^{\lambda_f}$$

which is a key input for the maximization problem of the intermediate producers. The economy is populated by a continuum of intermediate goods firms $i \in (0, 1)$, who use the technology:

$$y_t(i) = A_t k_t(i)^\gamma h_t(i)^{1-\gamma}, \quad (13)$$

with $0 < \gamma < 1$, where $k_t(i)$ is the firm's capital input and $h_t(i)$ is labor input. The capital is rented from the entrepreneur at rental rate r_t . Productivity A_t is common across firms. Labor and capital are hired in competitive markets at the real wage w_t and rental rate r_t , respectively. The capital is rented from the entrepreneurs, while the labor is rented from the workers unions described in the next section. The firm's profit, written in unit of the final good, is given by:

$$\mathcal{P}_t(i) = p_t(i) y_t(i) - w_t h_t(i) - r_t k_t(i), \quad (14)$$

where $p_t(i)$ is the relative price of intermediate good (i) in terms of the final good (that is, $p_t(i) = P_t(i)/P_t$, where $P_t(i)$ is the price of intermediate good i). Prices are sticky as in Calvo (1983). Specifically, each firm can readjust nominal prices with probability $1 - \zeta_p$ in each period and we denote the optimal equilibrium price by p_t^* but it can be shown the the optimal price is the same across firms that get to adjust their price.

$$p_t(i) = \begin{cases} p_{t-1}(i) & \text{with probability } \xi_p \\ p_t^* & \text{with probability } 1 - \xi_p \end{cases}, \quad (15)$$

The firm discounts its profit by a the nominal discount factor $\beta^s \Xi_{t+s}^p$. The firms are committed to supplying whatever output $y_t(i)$ is demanded at the price given by $p_t(i)$.

The intermediate goods producers problem: The problem of the intermediate goods producers is to choose $\{h_t(i), k_t(i), p_t(i)\}$ by maximizing the current and future discounted profits given by (14) subject to (12)-(15) taking as given $\{r_t, w_t, A_t, P_t, Y_t, \Xi_t^p\}$

2.5 Labor aggregator

There are two kinds of labor inputs, an intermediate labor input, $h_t(\omega)$, and a final labor input h_t produces by a competitive firm that buys the intermediate labor input. The firm that supplies the final labor input does so by combining a continuum of the intermediate labor input according to:

$$h_t = \left[\int h_t(\omega)^{\frac{1}{1+\lambda_\omega}} d\omega \right]^{1+\lambda_\omega}. \quad (16)$$

but we describe the supply decisions of the household that give rise to $h_t(w)$ in the next section. The final labor input producers buy the intermediate labor input on the market, package h_t according to (16) and resell it to consumers. These firms maximize profits in a perfectly competitive environment. Their problem is:

$$\begin{aligned} \max_{y_t, y_t(i)} \quad & h_t - \int_0^1 w_t(\omega) h_t(\omega) d\omega \\ \text{s.t.} \quad & h_t = \left[\int h_t(\omega)^{\frac{1}{1+\lambda_\omega}} d\omega \right]^{1+\lambda_\omega} \end{aligned} \quad (17)$$

Final labor input producers problem: The problem of the producer of final labor input is to maximize (17) by choice of $h_t(\omega)$ taking $w_t(\omega)$ as given.

2.6 Workers

The maximization problem of the final goods producers gives rise to a demand function for the intermediate good given by

$$h_t(\omega) = \left(\frac{w_t(\omega)}{w_t}\right)^{-\frac{1+\lambda_\omega}{\lambda_\omega}} h_t \quad (18)$$

where

$$w_t = \left[\int_0^1 w_t(\omega)^{\frac{1}{\lambda_f}} di \right]^{\lambda_f}$$

which is a key input for the maximization problem of the workers household. The economy is populated by a continuum of *workers* $\omega \in (0, 1)$, all belonging to the same family, but supplying differentiated labor $h'_t(\omega)$.¹ Consumption c'_t , nominal debt b'_t and equity n'_t are going to be the same for all workers within the family. The family's flow of funds is given by:

$$c'_t + q_t(n'_{t+1} - \lambda n'_t) + p_t(m'_{t+1} - m'_t) + \frac{b'_{t+1} - R_{t-1}b'_t}{P_t} \leq r_t n'_t + \int \frac{W_t(\omega)}{P_t} h'_t(\omega) d\omega + C(I_t) + \int \mathcal{P}(i) di - \tau_t^w, \quad (19)$$

where $W_t(\omega)$ are nominal wages, τ_t^w are taxes and we assume that workers receive the profit from the firms and capital producers. The family planner's objective function is given by:

$$E_t \sum_{s=t}^{\infty} \beta^{s-t} U[c'_s - \int \frac{\nu_0}{1+\nu} h_s(\omega)'^{1+\nu} d\omega], \quad (20)$$

where $U[\cdot]$ is increasing and strictly concave, $\nu_0 > 0$, $\nu > 0$. Workers cannot borrow:

$$n'_{t+1} \geq 0, \quad (21)$$

$$b'_{t+1} \geq 0. \quad (22)$$

The household chooses consumption and asset holding. It does not, however, select labor supply directly. Instead it chooses a wage rate at which to supply labor, and is then committed to supplying whatever labor demanded at that wage rate. The workers cannot select wages freely, however. Instead the wage is set according to a contract

¹Since we assume that the representative family takes the aggregate wage as given, one should really be assuming a continuum of representative families, but we omit this additional layer of notation.

that has stochastic duration la Calvo. Specifically, the worker can readjust wages with probability $1 - \zeta_w$ in each period and we denote the optimal wage in case of adjustment as W_t^* . Hence wage setting is subject to the constraint

$$w_t(\omega) = \begin{cases} w_{t-1}(\omega) & \text{with probability } \xi_p \\ w_t^* & \text{with probability } 1 - \xi_p \end{cases}, \quad (23)$$

The workers problem: The problem of the worker is to choose $\{c'_t, W_t(\omega), n'_{t+1}, b'_{t+1}\}$ by maximizing (20) subject to (18)-(23) taking as given $\{r_t, w_t, R_t, h_t, P_t, \mathcal{P}(i)\}$

2.7 The government

The central bank's policy amounts to an interest rate rule:

$$R_t = R_* (\pi_t / \pi_*)^{\psi_1} e^{\epsilon_t^R}, \quad (24)$$

where π^* is chosen by the central bank. Reserves B_t are assumed to be in zero net supply:

$$B_{t+1} = 0. \quad (25)$$

In absence of intervention, the government budget constraint is: The government transfers seignorage back to the workers:

$$p_t(M_{t+1} - M_t) = \tau_t, \quad (26)$$

but since the among liquid assets issued by the government is constant:

$$M_{t+1} = M, \quad (27)$$

taxes are also zero.

In case of intervention, the amount of equity \tilde{N}_t^g purchased by the government at the beginning of period t follows:

$$\tilde{N}_t^g = K_* \xi_1 \left(\frac{\phi_t}{\phi_*} - 1 \right). \quad (28)$$

which implies that $N_*^g = 0$. Next, we need a rule for financing the equity purchases. We assume that all the financing occurs via debt issuance:

$$p_t(\tilde{M}_t - M_t) = q_t(\tilde{N}_t^g - N_t^g). \quad (29)$$

Let us rewrite the government budget constraint. We write it by splitting period t into two parts for the sake of exposition: from midnight (t) to the intervention (\tilde{t}) and then from the intervention to $t + 1$. From midnight (t) to the intervention (\tilde{t}) no income is earned and nothing depreciates. Hence the government budget constraint is:

$$q_t \tilde{N}_t^g - p_t \tilde{M}_t = q_t N_t^g - p_t M_t. \quad (30)$$

This is the same constraint as (29) so it nets out. This is not surprising since all we are saying is that the government is financing the capital acquisition by issuing debt. From the intervention (\tilde{t}) to the midnight of next period ($t + 1$) the intertemporal budget constraint is:

$$q_t N_{t+1}^g - p_t M_{t+1} + \tau_t = q_t \lambda \tilde{N}_t^g - p_t \tilde{M}_t + r_t \tilde{N}_t^g, \quad (31)$$

that is, the government is (i) earning income on the capital it bought, and at the same time, (ii) the capital depreciates. We assume the following law of motions from \tilde{N}_t^g to N_{t+1}^g and \tilde{M}_t to M_{t+1} :

$$N_{t+1}^g = \tilde{N}_t^g \quad (32)$$

$$M_{t+1} = \tilde{M}_t \quad (33)$$

and the budget constraint boils down to:

$$\tau_t = -(1 - \lambda) q_t \tilde{N}_t^g + r_t \tilde{N}_t^g, \quad (34)$$

which says that the government pays upkeep to the newly acquired capital by using the capital income and, if not enough, extracting resources out of the workers.

2.8 Resource constraints

Below are the resource constraints that need to be satisfied for the equilibrium.

$$\int h_t(i) = h'_t, \quad (35)$$

$$\int y_t(e) = I_t[1 + S(\frac{I_t}{I_*})] + \int c_t(e) + c'_t, \quad (36)$$

$$M_t = \int m_t(e) + m'_t, \quad (37)$$

$$0 = \int b_t(e) + b'_t, \quad (38)$$

$$\int k_t(\cdot) = \int n_t(e) + n'_t + N_t^g, \quad (39)$$

where $I_t = \int i_t(e)$.

3 Characterizing a solution

The Appendix shows the first order conditions of the maximization problems listed in the equilibrium definition. It also shows how they can be aggregated so the equilibrium can be characterized in terms of aggregate variables. We take this set of equations and find a steady state of the model, also shown in the appendix. We then approximate the solution around this steady state. The resulting set of equations is linear, apart from the fact that we keep track of that the nominal interest rate cannot be lower than zero. Our main focus will be on solving the model, when it is subject to a shock to ϕ_t . We will see that the zero bound will be binding in this case, and we use the solution method described in Eggertsson (2008) to take account of the zero bound.

4 Calibration

We calibrate the model at quarterly frequency. The preference and technology parameters correspond to standard values in the business cycle literature. We fix the subjective discount factor β to 0.99 and the inverse Frisch elasticity of labor supply ν to 1. We choose a capital share γ of 1/3 and an annual depreciation rate of 10% ($\lambda = 0.975$). The

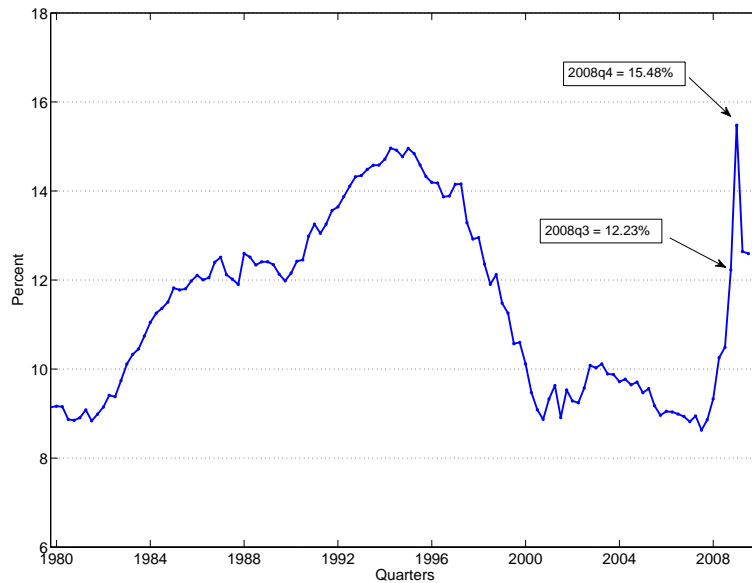


Figure 2: The liquidity share in the data

average duration of price and wage contracts is equal to 3 quarters ($\zeta_p = \zeta_w = 2/3$). For prices, this value lies roughly in the middle of the estimates of Bils and Klenow (2004) and Nakamura and Steinsson (2008).

The literature on investment spikes suggests between 20% (Doms and Dunne, 1998) and 40% (Cooper, Haltiwanger and Power, 1999) of U.S. manufacturing plants adjust their capital each year. Based on this evidence, we calibrate the probability of receiving an investment opportunity in each quarter \varkappa to 7%. This value probably represents an upper bound for the average frequency of investment to the extent that in the data very few plants adjust their capital stock more than once a year.

As we have no evidence to separately identify the steady state value of the borrowing and resaleability constraint, we set $\theta = \phi$. We choose the steady state value of the resaleability constraint ϕ to match the average post-war liquidity share, defined as

$$ls_t \equiv \frac{p_t M_{t+1}}{p_t M_{t+1} + q_t K_{t+1}}.$$

We use data from the U.S. Flow of Funds between 1952q1 and 2008q4 to construct the

empirical counterpart of the liquidity share in the model. Our measure of liquid assets consists of all liabilities of the Federal Government, that is, Treasury securities (L.106 line 17) net of holdings by the monetary authority (L.106 line 12) and the budget agency (L.209 line 20) plus reserves (L.108 line 26), vault cash (L.108 line 27) and currency (L.108 line 28) net of remittances to the Federal Government (L.108 line 29). All other assets in the U.S. economy fall into our notion of capital stock. We consolidate the balance sheet of households, non-corporate and corporate sector to obtain the market value of aggregate capital. For households, we sum real estate (B.100 line 3), equipment and software of non-profit organizations (B.100 line 6) and consumer durables (B.100 line 7). For the non-corporate sector, we sum real estate (B.103 line 3), equipment and software (B.103 line 6) and inventories (B.103 line 9). For the corporate sector, we obtain the market value of the capital stock by summing the market value of equity (B.102 line 35) and liabilities (B.102 line 21) net of financial assets (B.102 line 6). We then subtract from the market value of capital for the private sector the government credit market instruments (B.106 line 5), TARP (B.106 line 10) and trade receivables (B.106 line 11). Figure 2 shows the evolution of the liquidity share over the sample. Its average value is 12.64%, which implies a steady state value for the resaleability constraint of 11%. The figure also shows that at the apex of the financial crisis (i.e. right after Lehman's collapse) the liquidity share jumped to to 15.48% in 2008q4 from a value of 12.23% in 2008q3 consistent with its historical average.

Two qualifications are in order. First, no data is available for the physical capital stock of the financial sector. Our guess is that this item should probably be small. Second, consistently with the model, our calculations exclude assets and liabilities versus the rest of the world. The liquidity share calculated taking into account the foreign sector averages 10.65% over the sample period and exhibits very similar dynamics.

5 Simulating a Financial Crisis while abstracting from the zero bound

This section describes how we capture the financial crisis and the response of macroeconomic and financial variables. We feed the model with an innovation to the process for the liquidity shock ϕ_t . The persistence of the liquidity shock is set equal to 0.75, implying that the half-life of the shock is slightly less than four quarters.

We jointly calibrate the size of the shock and the intensity of the policy response (the feedback coefficient ξ in the intervention rule) to hit two targets: (i) A 20% increase in the liquidity share consistent with the evidence between 2008q3 and 2008q4; (ii) A \$1 trillion government intervention consistent with the increase in the asset side of the Fed's balance sheet after the collapse of Lehman Brothers.

In the model, the secondary market for equity almost shuts down on impact and slowly recovers thereafter. The liquidity shock depresses the expected return on equity for an entrepreneur with an investment opportunity next period. This effect is evident in the left-hand side of the no-arbitrage equation

$$\begin{aligned} \varkappa \mathbb{E}_t \left\{ \frac{1}{C_{t+1}^{si}} \left[\frac{p_{t+1}}{p_t} - \frac{r_{t+1} + \lambda(\phi_{t+1}q_{t+1} + (1 - \phi_{t+1})q_{t+1}^R)}{q_t} \right] \right\} \\ = (1 - \varkappa) \mathbb{E}_t \left[\frac{1}{C_{t+1}^{ss}} \left(\frac{r_{t+1} + \lambda q_{t+1}}{q_t} - \frac{p_{t+1}}{p_t} \right) \right]. \end{aligned}$$

Moreover, the liquidity shock also depresses investment

$$(1 - \theta q_t)I_t = \varkappa \{ \beta [p_t M_t + (r_t + \lambda \phi_t q_t)K_t] - (1 - \beta)(1 - \phi_t)\lambda q_t^R K_t \}. \quad (40)$$

These two equations are the heart of the transmission mechanism of the liquidity shock and clarify why the KM model is, at least qualitatively, capable of explaining important features of the financial crisis.

5.1 Impact on Macroeconomic and Financial Variables

The main question we are interested in, however, is quantitative. In this section, we investigate whether the model can account for a significant portion of the movement in macroeconomic and financial variables observed in the data.

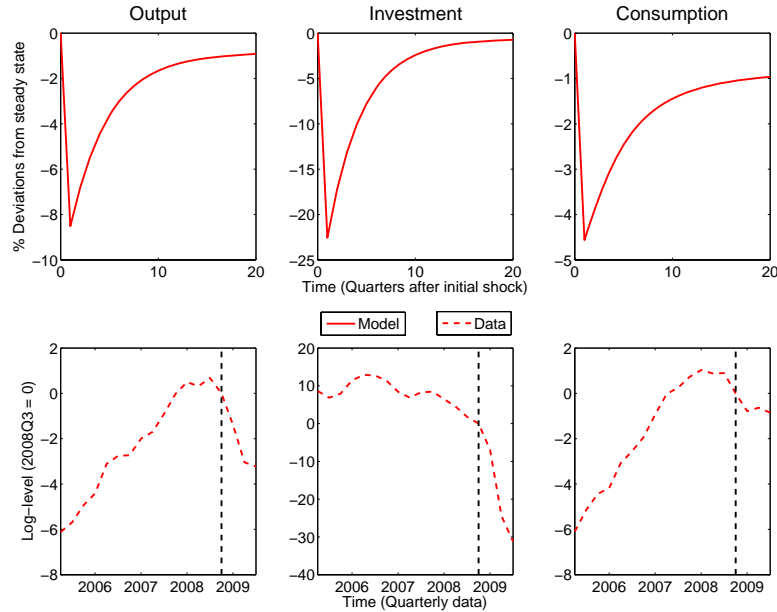


Figure 3: The response of macro variables to the liquidity shock.

The impact of the shock on macroeconomic variables is sizable and comparable with the data in terms of magnitudes (see figure 3). At the time of the shock, investment drops by more than 20%, roughly two-thirds of the cumulative drop in the data in the three quarters after the Lehman bankruptcy. The model partially overestimates the impact on output and consumption relative to the data.² Real activity drops by about 8.5% in the model, compared to an actual decrease just above 3%. Consumption falls by about 4.5% in the model versus a reduction of roughly 1% in the data.

Nominal rigidities play a central role in explaining the contemporaneous drop of all macroeconomic variables. If prices and wages were fully flexible, the liquidity shock would essentially have a redistributive effect. When entrepreneurs find harder to sell equity on their balance sheet to finance a new project, investment tanks. However, since the liquidity shock leaves productivity unchanged, the negative effect on output is very mild, driven by slower capital accumulation. Therefore, consumption increases on

²The national income and product account in the model, however, excludes government spending and the trade balance.

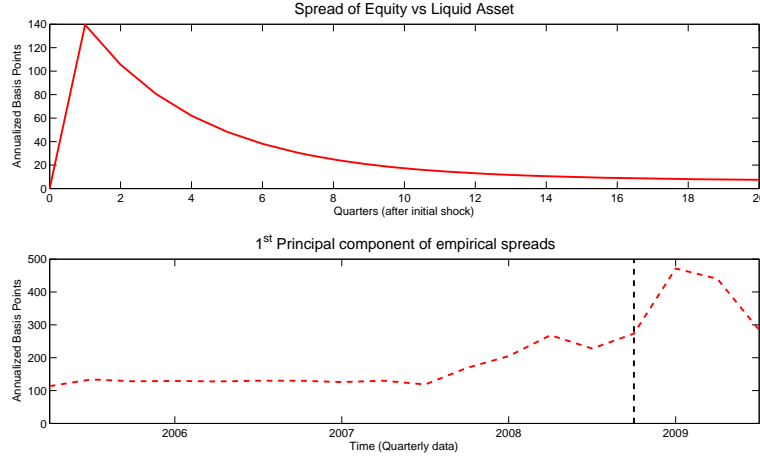


Figure 4: The response of financial variables to the liquidity shock.

impact.

Price rigidities contribute to amplify the negative impact of the liquidity shock on real activity because now output becomes demand-determined. Firms would ideally reduce their price in response to the liquidity shock but the staggered price setting mechanism prevents the full adjust to take place. In addition, sticky wages generate a drop in consumption because firms substantially cut hours so that workers' labor income takes a negative hit.

Overall, the model is consistent with the adjustment of output, consumption and investment observed in the data following the financial crisis of the fall of 2008.

The liquidity shock also generates a non-negligible response of financial variables. Figure 4 displays the spread of equity versus the liquid asset, defined as the difference in expected returns between the two type of assets

$$\Psi_t^{km} \equiv \mathbb{E}_t \left(\frac{r_{t+1} + \lambda q_{t+1}}{q_t} - \frac{p_{t+1}}{p_t} \right). \quad (41)$$

The liquidity shock causes this spread to increase by slightly less than 150 annualized basis points. So far, we have postulated that the government intervenes in direct response to the liquidity shock ϕ_t . However, we can easily map the intervention in a response to the spread in (41). The calibrated government intervention corresponds to a swap of almost \$900 billion worth of private equity for liquid assets for every 100 annualized basis point increase in Ψ_t^{km} .

The spread in the model has no immediate empirical counterpart. However, the bottom panel of figure 4 shows that our results are consistent with the behavior during the crisis of the first principal component extracted from a number of spreads between U.S. Treasury securities at various maturities and corporate bonds of different ratings.³

The model also produces an increase in the price of the liquid asset p_t relative to the price of equity q_t . This finding is intuitive. The liquidity shock makes equity less liquid. Entrepreneurs find harder to finance investment by selling equity on their balance sheet. Therefore, the liquid asset becomes relatively more valuable. Interestingly, this result is consistent with the “flight-to-quality” observed during the last quarter of 2008.

The bottom line is that our simulated crisis generates movements in macroeconomic and financial variables following a liquidity shock in line with their empirical counterparts during the last months of 2008.

5.2 The Quantitative Effects of Government Intervention

Our simulation of the financial crisis includes the effects of government intervention on macroeconomic and financial variables. A natural question, then, is to which extent government intervention prevented a more severe downturn in economic activity and additional stress in financial markets.

Figure 5 compares the baseline scenario with the counterfactual outcome under no intervention. In the absence of intervention, output, would have dropped on impact an additional 31% relative to baseline. Consumption and investment would have suffered further deteriorations of similar magnitude (37% for consumption, 27% for investment).

³Thanks to Tobias Adrian for providing us with the data.

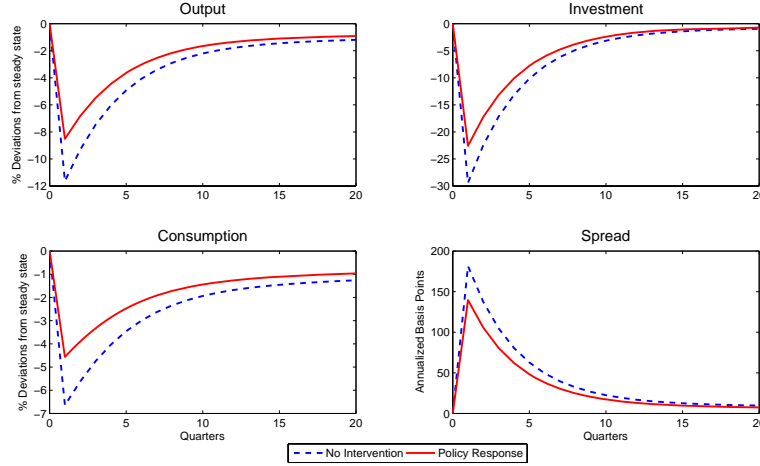


Figure 5: Counterfactual I - No intervention.

The government swap of liquid for illiquid assets positively influences investment

$$(1 - \theta q_t)I_t = \varkappa \left\{ \beta \left[p_t \tilde{M}_t + (r_t + \lambda \phi_t q_t) (K_t - N_t^g) \right] - (1 - \beta)(1 - \phi_t) \lambda q_t^R (K_t - N_t^g) \right\},$$

where now \tilde{M}_t is the higher quantity of liquid asset available to investing entrepreneurs after the swap. Moreover, the intervention also supports consumption

$$C_t = (1 - \beta) \left\{ p_t \tilde{M}_t + [r_t + (1 - \varkappa + \varkappa \phi_t) \lambda q_t + \varkappa (1 - \phi_t) \lambda q_t^R] (K_t - N_t^g) \right\}.$$

The intervention is beneficial also for financial variables. Spreads would have increased by 40 annualized basis points more than in the baseline while the relative price of liquid to illiquid asset would have increased an extra 1%.

Figure 6 plots the effects of alternative interventions. The green dashed line corresponds to an intervention twice as big than the baseline. The blue dash-dotted line shows that an intervention of about \$3.68 trillions would roughly stabilize output completely. In this case, investment would drop by about 3.5% and spreads would increase only by about 20 annualized basis points.

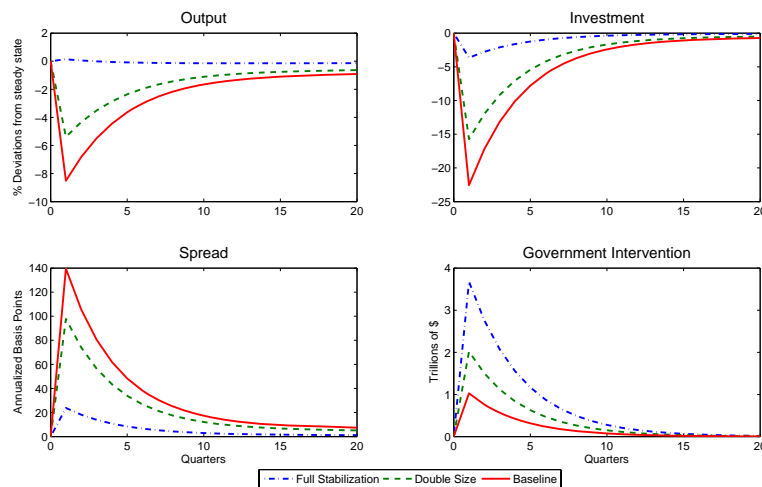


Figure 6: Counterfactual II - Alternative interventions.

6 Simulating a Financial Crisis with the zero bound: The Great Escape?

So far we have studied the behavior of the model in environment that does not take explicitly into account the fact that the short term nominal interest rates cannot be zero. The simulation in the past section, in fact, implied that nominal interest rates had to be significantly negative in order to be consistent with the Taylor rule we assumed. Does this have important quantitative effect? In this section we show that the answer to this question is unambiguously yes.

From a practical point of view it is also crucial to incorporate the zero bound into the analysis. As inspection of figure 1 suggests, it was only once the Fed approached the zero bound in the fall of 2008 that the non-standard policy was put into overdrive. This was undoubtedly motivated by the fact that traditional monetary policy – cutting interest rates – was reaching it’s limit. What would have happen in the absence of the non-standard policy, once the Fed hit zero interest rates?

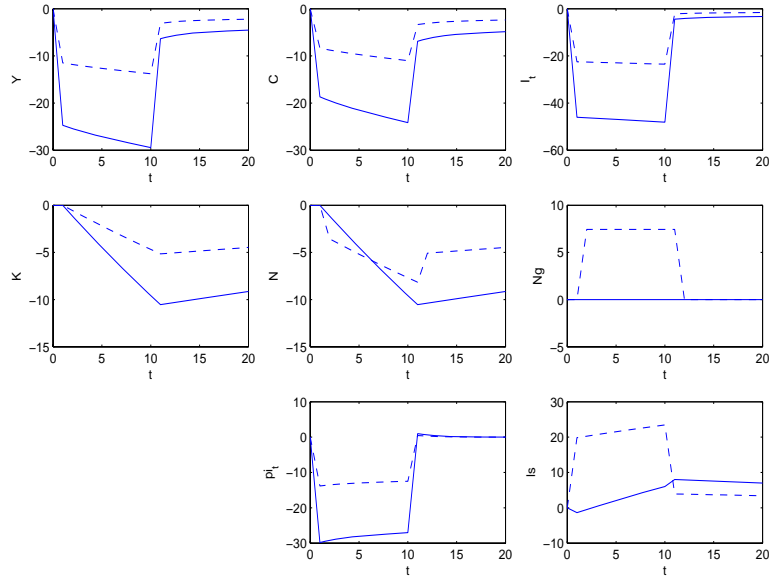


Figure 7: The effect of policy taking the zero bound into account.

To solve the model we now assume that the shock ϕ_t follows a two state Markov process. In period 0 the shock unexpectedly declines to $\phi_t = \phi_L$ and then reverts to steady state with probability α in each period, so that its implied persistence is $1 - \alpha$. We calibrate this parameter, as in last section, as 0.75. We pick ϕ_L and the non-standard policy reaction function in the same way as before. We assume the same policy reaction function as before, but now assume that if it implies negative nominal interest rate, the Fed sets them at 0.

Figure 7 shows the numerical experiment with and without non-standard policy intervention. The figure shows one particular contingency, i.e., if the shock ϕ_t stays in the "low" state for 10 quarters. As the figure reveals the intervention prevents a second Great Depression. In the absence of intervention output would have collapsed by about 30 percent. Meanwhile, with intervention, output contracts by around 10 percent. This suggest that the "multiplier", i.e. the effect on aggregate output of one dollar in spending is higher 2 (note that we express N_g as fraction of steady state output in the figur above) Observe, than in contrast to other stimulus measures, such as government spending, the

government makes money on this intervention, since they will resell the asset once the intervention is finished at a profit.

As the figure reveals, there is much larger effect of the intervention at zero interest rate than under normal circumstances. The reason for this is that at zero interest rate the intervention will not result no change in the nominal interest rate. The intuition is much the same as discussed in some detail in Eggertsson (2009) for the case of government spending.

7 Conclusions

In this paper we studied the effect on non-standard monetary policy using a theory of credit friction proposed by Kiyotaki and Moore (2008). We found that non-standard policy can have large effects. This is particularly true at zero interest rates. We showed a numerical example that in the absence of non-standard, the model economy generates the Great Depression.

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8 Appendix

<to be added>