2017

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Original Publication Citation

Yagihashi, T. (2017). How costly is a misspecified credit channel DSGE model in monetary policymaking? *Economic Modelling*, 1-51. doi:10.1016/j.econmod.2017.08.023

How Costly Is a Misspecified Credit Channel Model in Monetary Policymaking?

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March, 2017

Abstract

In general, misspecified models can cause harm through suggesting policies that would in reality lead to destabilization of the economy as well as through limiting policy options and thus preventing the policymaker from achieving the first-best outcome. This paper specifically examines whether the choice of credit market frictions in new-Keynesian DSGE models matters in the context of monetary policymaking. We conduct a simulation exercise in which a financial crisis occurs and the monetary policymaker shifts its policy to combat the crisis. In choosing the new policy, the policymaker uses a credit channel model that suffers from a misspecification in the type of credit market friction. We find that the policymaker would choose a policy that not only destabilizes the economy but also performs considerably worse relative to an alternative policy that would have been chosen under a correctly specified model. We further demonstrate that allowing the use of public financial intermediation as a policy option plays a key role in the above result. Finally, we show that using a more flexible policy rule specification or reassigning stabilization objectives can mitigate the problem of model misspecification with varying success.

Keywords: DSGE model, Financial Accelerator model, credit market friction

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1 Introduction

Since the global financial crisis of 2008, many economists have claimed that the environment in which monetary policy operates has drastically changed (Blanchard *et al.*, 2010; Caballero, 2010; Quadrini, 2012). In particular, it has become evident that the monetary transmission mechanism through supply of credit ("credit channel") matters greatly in times of crisis, which has led central bankers to adopt credit channel models in their routine policy analysis.[1]

Around the same time, we have also witnessed the surge of a new generation of credit channel models, attempting to model the economy through a refined treatment of the credit channel. One common feature of these models is that they explicitly model financial institutions along with their detailed balance sheet structures.[2] This is in sharp contrast to the earlier generation of credit channel models, in which the role of financial institutions is modeled as mostly passive or obscured.[3]

The recent shift in modeling strategy has been largely motivated by the following observations during the financial crisis of 2008. First, the disruption in the interbank loan market constrained the financial sector's ability to borrow funds, which led to an instant spike in many risk-spread measures. Second, the deterioration of asset prices, combined with the deleveraging of the entire financial sector, left non-financial firms with limited borrowing capacity. Finally, the monetary policymaker took various non-standard measures during the period following the crisis in an effort to reduce the credit-related problems and stabilize the economy. These observations point to the need to rethink how credit market frictions should be modeled and what the role of government should be in a standard credit channel model.

[1]In the pre-crisis era, it was customary to use arbitrary dynamic equations as proxies for "credit constraints, house price effects, confidence and accelerator effects" (Harrison *et al.*,2005). For more details on past practice in the central bank community, see Bayoumi *et al.* (2005), Coenen *et al.* (2007), and Erceg *et al.* (2006).

[2]For example, see Adrian and Shin (2010), Christiano *et al.* (2010), Christiano and Ikeda (2014), Cúrdia and Woodford (2010a, 2011), He and Krishnamurthy (2013), and Meh and Moran (2010).

[3]For the few exceptions seen during the pre-crisis era, see Chari *et al.*(1995), Goodfriend and McCallum (2007).

Given the numerous ways to specify the credit channel, it has become ever more important to examine whether and to what extent it matters to correctly specify the type of credit market friction in the context of monetary policymaking. To answer this question, we utilize two credit channel models widely used in the literature. The first model is Gertler and Karadi's (2010, GK) credit channel model. The model assumes that financial institutions do not have an effective commitment technology in honoring the debt contract and hence become constrained through their own balance sheets. In contrast, government is assumed to be free of such a constraint and thus is justified to engage in financial intermediation as a means to combat the financial crisis. This idea of government serving as an independent facilitator of financial intermediation has become quite popular in analyzing monetary policy during the financial crisis and is incorporated in many recent credit channel models.[4] In our simulation we treat this model as the "data-generating model" that represents the data-generating process in the real world.

The second model is Bernanke *et al.*'s (1999, BGG) credit channel model. This model assumes that lenders do not know the productivity of individual borrowers and need to pay agency costs in order to verify the financial state of the borrowers. In determining which borrower should receive credit, the monetary policymaker is just as uninformed as the private lenders, hence its policy tool is confined to the conventional interest rate policy. The BGG model received broad attention from monetary policymakers before and during the time of crisis. In January of 2008, the Federal Reserve governor Mishkin stated in his speech that the financial accelerator mechanism in the BGG model describes well the nature of macroeconomic risk that the monetary policymaker faces (Mishkin, 2008). Many central banks, such as the European Central Bank, the Bundesbank, and the Riksbank, are said to have formally incorporated the BGG-style credit channel into their DSGE models in the years following the crisis. Several empirical studies have shown that the credit market friction in the BGG model is also empirically relevant,[5] which has helped this model to become one of the most widely used credit channel models within

[4] See for example, Cúrdia and Woodford (2010b), Del Negro *et al.*(2016).
[5] See for example, Christensen and Dib (2008) and Christiano *et al.* (2014).

and outside the academic community. In our simulation, this model will serve as the "approximating model", which will be used by the hypothetical policymaker to estimate model parameters and calculate the optimized policy rule parameters that minimize the quadratic welfare loss measure. The above choices of using GK model as our "true" data-generating model and BGG model as our "misspecified" approximating model is largely motivated by the historical fact that at the onset of the financial crisis many central bankers were not equipped with much of the credit channel models that were reflecting the empirical facts learned through the crisis.

Using these settings, we conduct a battery of experiments. First, we check whether a misspecification in the type of credit market friction leads to a quantitatively large shift in the estimates of the model parameters. Second, we examine how the monetary policy rule suggested by the misspecified BGG model (BGG-optimal policy rule) performs in minimizing welfare loss during the financial crisis. Third, we compare how the BGG-optimal policy rule performs against the monetary policy rule suggested by the correctly-specified GK model (GK-optimal policy rule). Finally, we study whether the use of a more flexible policy rule specification with additional credit channel variables or assigning alternative stabilization objectives to the policymaker can mitigate the problem of model misspecification.

Our main results can be summarized as follows. First, we find that parameters estimated using the BGG model remain relatively stable over different phases of the financial crisis. Second, we show that using the misspecified model leads to a slight increase in welfare loss. But when compared to the GK-optimal policy rule (which is unattainable given the built-in misspecification), the BGG-optimal policy rule performs notably worse. Third, further analysis reveals that public financial intermediation, which is ruled out in the BGG model, plays a key role in achieving the first-best outcome. Lastly, adding a lagged risk spread in the optimal policy rule is found to reduce the welfare loss, although it still falls short of the case with the GK-optimal policy rule.

This paper makes three main contributions to the monetary DSGE literature: First, the paper confirms that the BGG model is relatively immune to parameter invariance problems, even in the case of model misspecification considered in this paper. Parameter invariance, at least in approximate terms, is important for any models to be used as credible tools for policy analysis in the sense of Lucas (1976). It is particularly important within the DSGE literature, because it is customary to interpret the change in model parameters as structural change, rather than a consequence of model misspecification (e.g., Canova, 2009; Smets and Wouters, 2005). Our result demonstrates that the BGG model does a decent job in estimating model parameters, providing the policymaker with a reasonably accurate description of the crisis.

Second, our paper is unique in that we examine whether an expanded monetary policy rule with credit channel variables and assigning alternative stabilization objectives to the policymaker, both of which are feasible in the misspecified model, can be used to reduce the cost of credit channel misspecification. While several studies have independently examined the benefit of these alternative policies,[6] we are not aware of any study that consider these policies as a means to correct the stabilization bias in a misspecified DSGE model.

Finally, the type of misspecification considered in this paper has not been explored by previous studies that also examine the consequences of model misspecification.[7] Many of the previous studies define their approximating model as a "simplified" representation of the more complicated data-generating model, which necessarily generates very different moments of endogenous variables. In our case, both the data-generating model and the approximating model generate similar moments for inflation, output, and interest rates through the financial accelerator effect. Therefore, observationally we cannot regard one as a simplified version of the other, nor can we say clearly which one provides a more "plausible" model dynamics in the sense of Faust (2012) by comparing the moments of key endogenous variables. Our approach may be particularly useful for policymakers who

[6]See for example, Christiano *et al.* (2008), Cúrdia and Woodford (2010b, 2015), Driffill *et al.* (2006), Gilchrist and Zakrajsek (2011), and Yagihashi (2011).

[7]See for example, An and Schorfheide (2007), Canova (2009), Canova and Sala (2009), Chang *et al.* (2013), Cogley *et al.* (2011), Cogley and Yagihashi (2010), Fernandez-Villaverde and Rubio-Ramirez (2007), Leeper and Sims (1994), Lubik and Schorfheide (2004), Lubik and Surico (2010), Rudebusch (2005).

wish to refine their baseline model by incorporating several off-the-shelf models but do not know the clear benefit of choosing one over the other. We also note that while many of the previous studies have used models with a relatively small number of equations as their simulation platform, both of our models share a larger number of the structural equations used in the model of Justiniano *et al.* (2010, JPT).[8] Thus our results can be seamlessly incorporated into monetary policy analysis, which typically utilizes more than just a handful of observables and shocks in estimating model parameters.

The next section explains the simulation exercise and models. We present in the third section the main results with regard to parameter changes and discuss policy implications. The fourth section conducts additional experiments on how to improve model outcomes. The last section summarizes this study and draws several conclusions from it.

2 Simulation Design

2.1 Models

2.1.1 Approximating Model

We use an extended version of Bernanke *et al.* (1999, BGG) as our baseline approximating model in this paper. The extension of the model is done by incorporating additional frictions (e.g., wage rigidity) and shocks (e.g., shock on marginal efficiency of investment) into the original model, so that the model is similar to what is now used in the macro literature as well as in actual policymaking. We describe the core part of the BGG model below, leaving the details for Appendix A.

The BGG model motivates credit market friction through a combination of ex-ante uncertainty regarding the individual borrower's productivity and the agency cost (called "bankruptcy cost" in BGG) required for the lender to verify the financial state of the borrower. The latter is known in the literature as the costly state verification problem, which is first introduced in Townsend (1979) and applied to many other credit channel

[8]This type of medium-scale DSGE models has been populated by empirical macroeconomic researchers such as Smets and Wouters (2003, 2005).

models.[9] To overcome these hurdles between the lender (called "financial intermediary" in BGG) and the borrower (called "entrepreneur" in BGG), the two parties agree to write a loan contract such that the lending rate becomes contingent on the borrower's balance sheet condition.[10] In aggregate, this relationship can be represented by the following equation

$$E_t R_{t+1}^k = \left(\frac{Q_t \overline{K}_t}{N_{t+1}} \right)^{\nu} R_t, \tag{1}$$

where R_{t+1}^k is the gross rate of return on capital that realizes in period $t+1$, R_t is the gross risk-free interest rate determined in period t, Q_t and $\overline{K_t}$ are the price and quantity of the borrower's assets (i.e., installed physical capital), and N_{t+1} is the net worth available at the beginning of period $t+1$. The positive credit market friction parameter ν is derived from solving the optimal contract problem between the borrower and the lender, taking into account both the size of the (unit) agency cost and the size of the individual productivity shock. Equation (1) implies that as the borrower becomes more indebted, a higher return on capital investment is needed to justify the loan contract. Any exogenous shock that affects the leverage ratio will be accompanied by an additional "financial accelerator effect" on the aggregate economy through the behavior of external financial premium, $E_t R_{t+1}^k / R_t$. This financial accelerator effect is further enhanced through the accumulation process of the borrower's net worth

$$N_{t+1} = \gamma_{BGG} \left[R_t^k Q_{t-1} \overline{K}_{t-1} - \left(R_{t-1} + \frac{AC_{t-1}}{Q_{t-1}\overline{K}_{t-1} - N_t} \right) \left(Q_{t-1} \overline{K}_{t-1} - N_t \right) \right] + W_{b,t} L_b, \tag{2}$$

where AC_{t-1} is the size of the bankruptcy cost incurred in period $t-1$, $W_{b,t}$ is the borrower's wage rate, L_b is the (fixed) labor supply, and γ_{BGG} is the survival rate of the borrower. Equation (2) states that the borrower's net worth is equal to the gross revenue from the capital investment net of the borrowing cost.

[9] See for example, Arellano *et al.* (2012), Carlstrom and Fuerst (1997), Fisher (1999), and Jermann and Quadrini (2012).

[10] We follow Christiano *et al.*'s (2014) approach that regards the borrower in the BGG model as financial institutions that invest in physical capital through their loans. To avoid confusion regarding the terms, we will use lender/borrower hereafter.

2.1.2 Data-generating Model

We use the model of Gertler and Karadi (2011, GK) as our data-generating model. As before, we focus on the core function of the model, leaving the details to Appendix A.

The GK model motivates the credit market friction differently from the BGG model. It assumes that the borrower (called "banks" in GK) has the option not to honor the debt contract and appropriate the funds. Because the lender (called "depositors" in GK) is fully aware of such a risk, the borrower is confined to expand its assets up to a certain leverage ratio.[11]

The threshold leverage ratio is determined by the condition that the benefit of continuing business for the borrower is matched to the benefit from reneging on the debt contract

$$\phi_t = \frac{\eta_t}{\lambda - \upsilon_t} \tag{3}$$

where η_t is the marginal value of the borrower's net worth, υ_t is the marginal value of the borrower's assets, and λ is the fraction of assets that the borrower can possibly divert. As parameter λ increases, or as variables η_t, υ_t fall, the borrower becomes more "balance sheet constrained" (Gertler and Karadi, 2011). The constraint is assumed to be binding at all times, and the strength of the constraint varies depending on the *expected* profitability of the borrower's business captured by variables η_t and υ_t. The net worth of the borrower grows as follows

$$N_{t+1} = \gamma_{GK}[(R_t^k - R_{t-1})\phi_{t-1} + R_{t-1}]N_t + \omega Q_t \overline{K}_{t-1} \tag{4}$$

where γ_{GK} is the survival rate of the borrower and ω is the proportional transfer from the lenders to the entering borrowers to be used as start-up funds. Equation (4) shows that the borrower's net worth is the sum of the gross revenue from capital investments and the

[11] Here lenders are not limited to households, who are the ultimate savers, but may also include other financial institutions that supply funds through the interbank loan market (Gertler and Kiyotaki, 2010). For the same reason, borrowers are not limited to financial institutions that accept deposits from households, but may also include a broader range of financial institutions that issue short-term debt contracts in the financial market.

gross return on the previous period's net worth. The revenue from capital investments is increasing in both the risk spread and the leverage ratio.

2.1.3 Similarities and Differences between the Models

The BGG and GK credit channel models share several common features. First, both models have common credit channel variables (risk spread and leverage ratio), which can be used as observables when estimating model parameters.[12] Second, the two models have the same number of structural shocks. These are monetary policy shock, technology shock, government spending shock, marginal efficiency of investment (MEI) shock, price markup shock, wage markup shock, preference shock, and risk premium shock. In particular, the MEI and risk premium shocks are considered to be especially important in examining the consequences of credit channel misspecification, as researchers have pointed out that these two shocks have played a prominent role in explaining the economic fluctuation during the financial crisis (Christiano *et al.*, 2014; Gali *et al.*, 2012). Third, in both models the main role of the risk spread is to amplify the effect of structural shocks, also known as the financial accelerator effect. Finally, the implied slow development of net worth serves as an internal propagation mechanism of the shocks.

The key differences of these models are as follows. First, the risk spread, which is at the core of both models, responds differently to the endogenous variables. In the BGG model, the risk spread (expressed in ratio of gross returns) responds contemporaneously to the leverage ratio, and the credit market friction parameter ν determines the magnitude of the response. In the GK model, the risk spread is indirectly associated with the leverage ratio through the expected profitability of the borrower's business. The credit market friction parameter λ affects how strongly the current leverage ratio responds to the expected future risk spread.

Second, in the BGG model the role of government in financial intermediation is limited. If we maintain the seemingly natural assumption that the government is as uninformed

[12]They can also serve as additional variables that possibly enter the Taylor rule or stabilization objectives. See Section 4 for more detail.

about the individual borrower's productivity as are the private lenders, then government would set their contract lending rate such that the agency cost is eventually covered by the borrower to avoid any loss. In such environment there is no strong justification for the government to actively intervene in the business of financial intermediation, which would result in crowding out the private lender.[13] In the GK model, the government is perceived to always honor its debt contract with the general public, which would free the government from the type of balance sheet constraint that private financial institutions must face at all times. Therefore, there is a potential efficiency gain for the government in conducting public financial intermediation, especially during crisis when private lenders face an unusually tight balance sheet constraint.

In sum, our model choice implies that the policymaker fully acknowledges the existence of credit market frictions, but fails to understand the *exact* nature of them, which could lead to misjudgment of the financial accelerator effect. In addition, the potential role of the government differs in the context of financial market intervention, which may lead to different economic stabilization outcomes in times of financial crisis.

2.2 Monetary Policy

2.2.1 Conventional Monetary Policy Rule ("Taylor Rule")

The basic instrument of monetary policy in both models is the nominal interest rate, which is allowed to respond to the endogenous variables in the economy. The monetary policymaker sets the interest rate following a modified version of the Taylor rule

$$R_t = R_{t-1}^{\rho_R} \left[(\Pi_t)^{\phi_\pi} (X_t)^{\phi_X} \left(\frac{X_t}{X_{t-1}} \right)^{\phi_{\Delta X}} \right]^{1-\rho_R} \exp\left(S_{mp,t}\right), \tag{5}$$

where Π_t is the gross inflation observed over time $t-1$ and t, X_t is the value-added output observed at time t. $\phi_\pi, \phi_X, \phi_{\Delta X}$ are the monetary policy parameters that can be freely

[13]Note that it is possible to hypothesize a world in which the government is designated to offer credit to lenders that is *junior* to private market debt, while using the taxpayer's money to cover the bankruptcy cost. In practice, such policy is rarely adopted because central banks, who is typically in charge of implementing the policy, are highly averse of incurring any loss through engaging itself in the financial intermediation.

chosen by the policymaker, whereas ρ_R is the parameter that reflects the policymaker's preference for gradually adjusting the policy rate.[14] $S_{mp,t}$ is the monetary policy shock modeled as

$$S_{mp,t} = (S_{mp,t-1})^{\rho_{mp}} \exp(e_{mp,t}), \tag{6}$$

$$e_{mp,t} \sim N(0, \sigma^2_{mp}).$$

The monetary policymaker chooses its policy parameters so as to minimize the following quadratic welfare loss measure, subject to the linearized model equations

$$\min_{\phi_\pi, \phi_X, \phi_{\Delta X}} L_0 \equiv \Gamma_t' W \Gamma_t, \tag{7}$$

$$\Gamma_t = [\widehat{\Pi}_t, \widehat{X}_t, \widehat{R}_t]'$$

where the hat on top of variables refers to deviation from the steady state. W is a 3-by-3 diagonal weighting matrix with entries $1, \lambda_X, \lambda_R$. The parameters represent the importance of the output and interest rate stabilization components relative to inflation.

The method of approximating the expected utility of households through the weighted average of the variances of selected variables has a long tradition in the macroeconomic literature.[15] This method has also been used by policymakers as a means to communicate policy objectives to the general public (Evans, 2011). One outstanding characteristic of the Equation (7) is that it includes interest rate smoothing as one of the objectives. Woodford (2003) shows that including this component results in a better stabilization outcome by making central bank behavior more predictable to the private sector. It is also in line with one of the Fed's statutory objectives for monetary policy, which is to foster a "moderate long-term interest rate" (Federal Reserve Act of 1977).

[14] There is some ambiguity within the monetary policy literature as to whether to treat ρ_R as a preference parameter or a policy parameter. We assume that the policymaker knows the value of ρ_R but does not intentionally adjust its value. This is because in practice, central banks communicate their policy intention through their *target* level of interest rate (= the terms in the large bracket) rather than through the speed of adjustment towards the level it targets. Woodford (1999) demonstrates that when ρ_R is freely chosen as a policy parameter, a "super-inertial" feedback rule ($\rho_R > 1$) becomes optimal, which contradicts the general empirical finding that ρ_R stays within the unit interval.

[15] See for example, Benigno and Woodford (2004, 2005), Clarida *et al.* (1999), Rotemberg and Woodford (1997), and Woodford (2002). For a comprehensive survey, see Benigno and Woodford (2012).

2.2.2 Non-standard Monetary Policy Rule ("Public Financial Intermediation")

We further assume that when using the correctly-specified GK model, the policymaker has an additional policy option to inject credit into the economy in response to the change in financial intermediaries' leverage ratio ("public financial intermediation"). This resembles the large-scale asset purchase implemented by the Fed during the financial crisis, in response to the deteriorating bank balance sheet. The fraction of publicly intermediated asset is determined by the leverage ratio of the borrower

$$\psi_t = \psi \phi_t^{\nu_g}, \tag{8}$$

where ν_g is the reaction coefficient chosen by the policymaker under the new policy regime in addition to ϕ_π, ϕ_X, and $\phi_{\Delta X}$ when minimizing the Equation (7). Gertler and Kiyotaki (2010) as well as Gertler and Karadi (2013) show that further modification of the model allow us to analyze the effect of an equity injection, which was implemented during the recent financial crisis.[16] When there is no crisis, public financial intermediation is not considered an option, i.e., $\nu_g = 0$.[17] In correspondence, the nationwide leverage ratio is redefined as

$$\phi_{c,t} = \frac{1}{1-\psi_t}\phi_t. \tag{9}$$

2.3 Timeline

To simulate the recent financial crisis, we prepare three events (financial crisis, policy shift, and end of financial crisis) and four time periods that are partitioned by these events. Following the approach of Cogley and Yagihashi (2010), we assume that (i) each period has the same length of sample period of T quarters, (ii) within each period, there is an immediate convergence to a new equilibrium (i.e., no learning), and (iii) the

[16] Note that our non-standard monetary policy rule of Equation (5) does not involve policies that were specifically aimed at solving the short-term *liquidity* problem (e.g., Commercial Paper Funding Facility) that were implemented by the Federal Reserve around the same time.

[17] Blanchard *et al.* (2010) provides further discussion on why public financial intermediation is not desirable in normal times.

policymaker knows the exact date of the transition from one period to another, so that model parameters in a given period can be estimated separately from another period.

Each period is characterized as follows:

1. The "Pre-crisis" period. Parameters related to the credit channel are set to the benchmark values that reflect the relatively tranquil period before the crisis. Policy parameters are initialized to the optimal values in the GK model (to be discussed later).

2. The "Crisis" period. Average risk spread increases and average leverage ratio decreases, both of which are directly observable to the public. In both the GK and the BGG models, these changes will translate into a larger credit market friction. In addition, the standard deviation of the risk premium shock increases. This increase is not directly observable to the public and needs to be estimated for the change to be acknowledged by the monetary policymaker. Policy parameters remain unchanged from the pre-crisis period.

3. The "Policy shift" period. First, the policymaker recalculates the credit market friction in the BGG model based on the observed changes in both the average risk spread and the average leverage ratio. Next, the policymaker estimates model parameters by matching the re-parameterized BGG model and the time series of eight observables in the crisis period (defined in the next subsection). Finally, he uses the newly estimated model parameters to calculate a new set of optimized policy parameters in the monetary policy rule (5).

4. The "Post-crisis" period. Average risk spread, average leverage ratio, and standard deviation of the risk premium shock all return to the pre-crisis level. Policy parameters remain unchanged from the policy shift period.

2.4 Estimation

In preparing for the policy shift, the monetary policymaker obtains parameter estimates by fitting the approximating BGG model to the observed data generated from the GK model. The process is equivalent to minimizing the distance metric known as the Kullback-Leibler Information Criterion

$$\arg\min KLIC = \int \log\left(\frac{p_{GK}(\mathbf{Y}|\boldsymbol{\theta}_{GK})}{p_{BGG}(\mathbf{Y}|\boldsymbol{\theta}_{BGG})}\right) p_{GK}(\mathbf{Y}|\boldsymbol{\theta}_{GK})d\mathbf{Y}, \tag{10}$$

where $p_i(\mathbf{Y}|\boldsymbol{\theta}_i)$, $i = GK, BGG$ represents the likelihood function, $\mathbf{Y}$ represents a vector of variables and $\boldsymbol{\theta}_i$ represents a (subset of a) vector of parameters that appear in both models. The vector of parameters $\boldsymbol{\theta}_i$ is further partitioned into private sector parameters and policy-related parameters

$$\boldsymbol{\theta}_i^{priv} = [h, \psi, \chi, S'', \xi_p, \iota_p, \xi_w, \iota_w, \rho_{mp}, \rho_A, \rho_G, \rho_\mu, \rho_p, \rho_w, \rho_b, rho_{rp}, \theta_p, \theta_w]', \tag{11}$$

$$\boldsymbol{\theta}_i^{pol} = [\phi_\pi, \phi_X, \phi_{\Delta X}, \rho_R]'. \tag{12}$$

The policy-related parameters (including ρ_R) are treated as being known to the policymaker and hence will be left out of the estimation. When the policymaker solves the KLIC with respect to $\boldsymbol{\theta}_{BGG}^{priv}$, the estimates converge in probability to the "pseudo-true" estimates $\widehat{\boldsymbol{\theta}}_{BGG}^{priv}$. Due to the presence of model misspecification, there will necessarily be asymptotic bias between $\boldsymbol{\theta}_{GK}^{priv}$ and $\widehat{\boldsymbol{\theta}}_{BGG}^{priv}$. In general, this bias can be "large" in the economic sense, *irrespective* of the size of T. Only under the circumstance that the approximating model is correctly specified, this bias is expected to vanish as T approaches infinity.

In our experiments, we make the following choices. First, we set our $\boldsymbol{\theta}_{GK}$ according to the posterior mean reported in JPT, which estimates the parameters using the sample period of 1954Q3 to 2004Q4. Their estimates on key parameters are in line with previous studies that use medium-scale DSGE models. Table 1 lists the actual parameter values of $\boldsymbol{\theta}_{GK}$.

Second, we choose $T = 8,000$ quarterly time series. To ensure that initial conditions have worn off, we first simulate $8,800$ quarterly observations for eight variables (explained below), then discard the first 800. Our intent of setting T to an extremely large value is to focus on the role of model misspecification and minimize the uncertainty that would potentially arise from limited data availability. As we will see in the analysis section, $T = 8,000$ is sufficient in making the standard error associated with the parameter estimates tiny, such that the we can be certain that the estimates have converged to the targeted pseudo-true values.

Third, when estimating the parameters $\boldsymbol{\theta}_{BGG}$, our policymaker utilizes prior information on these parameters. Note that priors are introduced to facilitate the numerical computation and to avoid the "dilemma of absurd parameter estimates" that are seen in many pure maximum likelihood estimations (An and Schorfheide, 2007). In limit the effect of the prior will be dominated by the large sample period and will have no effect on the pseudo-true values (Gelman *et al.*, 2000). We set the prior mean equal to $\boldsymbol{\theta}_{GK}$. Prior standard deviations are set equal to the estimates in JPT, and these values are provided in the last column of Table 1.

Finally, when estimating model parameters, the policymaker is assumed to observe eight macro variables. The number of observables is intentionally matched with the number of structural shocks in the approximating model to avoid indeterminacy. The list of variables used as observables are inflation, output, interest rate, consumption, investment, hours worked, wage rate, and risk spread. The first seven are fairly standard choices in the monetary DSGE literature. We include risk spread because Christiano *et al.* (2014) stress the importance of this variable being used as part of the observables in order for credit channel models to achieve a good fit with the data. This choice would thus give the BGG approximating model an advantage over the standard non-credit channel models in estimating model parameters.

2.5 Calibration

Table 2 summarizes the parameter values that are not estimated using the approximating model. Most parameter values are based on Justiniano *et al.* (2010), Gertler and Karadi (2011), and Bernanke *et al.* (1999).

There are a few credit channel-related parameters that take different values in the pre-crisis and crisis periods, depending upon how we define the financial crisis. In the GK model, the fraction of assets that can be diverted (λ) and the proportion of assets transferred to the entering bankers (ω) are chosen so that the targets for the average risk spread and leverage ratio are implied. We assume that the average risk spread increases from 100 basis points in the pre-crisis period to 150 basis points in the crisis period, reflecting the observed spike in various measures of risk spread.[18] We also assume that the leverage ratio for the pre-crisis period is five and that for the crisis period it falls to four. The level of leverage is close to the calibrated value in Gertler and Karadi (2010). The magnitude of deleveraging is matched to that in Tressel (2010), which estimated that the US leverage fell by 18% from 2007 to 2009.

Parameters used in the BGG approximating model are calibrated so that they target the same moments in the GK model. For example, uncertainty about the borrowing firm's investment project (σ_b) and bankruptcy cost (μ_b) are chosen so that the same average risk spread and leverage ratio as in the GK model are implied. These choices imply that the elasticity of the risk spread with respect to the leverage ratio (ν) increases from 0.0126 to 0.0175, whereas the annual default rate increases from 3.42% to 5.64% from the pre-crisis to the crisis period.[19]

For the risk premium shock, which was not estimated in JPT but appears in GK/BGG model specifications, we assume that the persistence parameter ρ_{rp} remains constant across periods, whereas the size parameter σ_{rp} increases from the pre-crisis period to the crisis period in a regime-switching manner (Dordal-i-Carreras *et al.*, 2016). The selected values are within the range estimated by Gali et al. (2012) and Smets and Wouters (2007).

For the policy-related parameter, we set the relative weight of the welfare loss function

[18] In determining the credible magnitude of the upward spike, we considered risk spreads associated with Baa corporate bond rates, short-term commercial paper rates (suggested by Gertler and Kiyotaki, 2010), and the LIBOR-OIS spread (suggested by Taylor and Williams, 2009).

[19] Note that the ν in our calibration is much smaller compared to other studies using the BGG model. In most of these studies, the credit channel parameters are calibrated or estimated by treating non-financial firms as borrowers. This leads to a lower target for the leverage ratio and a higher target for the risk spread than what we considered in our paper.

λ_X, λ_R following the values suggested in Woodford (2003). Policy parameters $\phi_\pi, \phi_X, \phi_{\Delta X}$ are initialized to the values that minimize the welfare loss in the "true" GK model during the pre-crisis period while ruling out public financial intermediation as a policy option (i.e., restricting ν_g to be zero). This setting ensures that we start our experiment from the optimal monetary policy rule, which would necessarily become sub-optimal once the crisis occurs.[20] Finally, the interest rate smoothing parameter ρ_R is set to 0.82 based on JPT's estimation.

2.6 Simulation Result

To double-check that our parameter choice for risk premium shock empirically makes sense, we report a 10-quarter forecast error variance decomposition for several main variables in Appendix Table A.1. The results are reasonably close to what past studies that utilize a medium-scale DSGE model have found.[21]

Appendix Table A.2 reports the change in volatility of the main variables (inflation, output, interest rate) across different periods. We find that the change in the standard deviation of the interest rate from pre-crisis to crisis period generated by the GK model exceeds that of the BGG model, while the changes for inflation and output in the GK model are slightly below those of the BGG model. However, the welfare loss as calculated in the Equation (7) shows similar increases in both the GK and the BGG models (+12.0%, +11.6%). This means that from the policymaker's viewpoint, the consequence of the crisis is similar in both models, and due to the similarity in outcome, it is difficult for the policymaker to infer whether the BGG model is a good approximating model or not.

[20] An alternative approach is to initialize the policy parameters to the BGG-optimal policy rule in the pre-crisis period. The policy parameters would be $\phi_\pi = 3.86, \phi_X = -0.47, \phi_{\Delta X} = 6.88$, which are not much different from the values that we adopt. Thus, for the sake of clarity in the later policy analysis, we decide to use the GK-optimal policy rule with $\nu_g = 0$ as our initial policy.

[21] For example, during the crisis period, the risk premium shock in our model explains 0.9% of the variation in inflation, 2.6% of output, and 4.5% of the interest rate. Smets and Wouters (2007) report that the same shock explains close to 1% of the variation in inflation, 5% of output, and 10% of the interest rate.

3 Results

3.1 Preliminaries: Parameter Invariance Problem

We first report the estimated model parameters in the BGG approximating model and examine how they differ across periods as a consequence of model misspecification.

Table 3 presents the pseudo-true values for the four periods (pre-crisis, crisis, policy shift, and post-crisis). Most of the standard errors are driven close to zero due to the large sample period we adopted in simulation. When focusing on the preference and technology parameters, we find that the BGG model does remarkably well in the crisis period, because most parameters remain close to the "true" values used in generating the data. In the policy shift period, the consumption habit parameter and the wage indexation parameter appear as two of the few notable exceptions.[22] This indicates that model misspecification in the BGG model manifests itself mainly as an asymptotic bias caused by the policy shift, rather than through the change in credit channel-related parameters.

Turning to the shock-related parameters, we see a somewhat larger influence of the financial crisis on the estimated parameters. For example, parameters associated with the MEI shock, the preference shock, and the risk premium shock notably deviate from the value used in the data-generating model during the crisis period. Since the MEI shock is often regarded as a proxy for financial market conditions, the observed change would be correctly interpreted as a disturbance in the financial market *by chance*.[23] However, for other parameters the change is purely a by-product of model misspecification and hence has no economic interpretations. Finally, the increase in the standard deviation of the risk premium shock from the pre-crisis (0.29) to the crisis period (1.07) is only marginally off from the values used in generating the data, which are set to 0.2 in the pre-crisis period and 1 in the crisis period. Thus the BGG model provides the policymaker a reasonably accurate description of the crisis.

[22]For the consumption habit parameter, the estimate is 0.90 as opposed to 0.78 in the data-generating model, whereas for the wage indexation parameter the estimate is 0.19 as opposed to 0.11 in the data-generating model.

[23]For discussions on the interpretation of the MEI shock, see Christiano *et al.* (2014), Hirose and Kurozumi (2012), and Justiniano *et al.* (2011).

The last column of Table 3 presents parameter estimates obtained during the post-crisis period. Most of the estimates return to the pre-crisis level. The small differences that remain in some cases reflect the different policies adopted during the pre- and post-crisis periods. This demonstrates that the effect of the policy shift on parameter estimates is minor in tranquil times.

One may wonder, at this point, whether a model without the credit channel can do an equally good job. To examine this, we repeated the entire exercise by using the "original" JPT model that does not feature an explicit credit channel as our approximating model. In this new experiment, the risk premium shock and the risk spread variable are dropped in the estimation process. The full estimation result is presented in Appendix Table A.3. We find that the asymptotic bias becomes larger and many of the parameters fail to remain invariant during the crisis period, as compared with the BGG model. Parameters related to the MEI shock and the preference shock incur the largest asymptotic bias among all parameters, likely absorbing the effect of the increased risk premium shock, which does not exist in the JPT model.

We conclude that the BGG model performs decently in terms of estimating the structural parameters during the financial crisis. The result is somewhat surprising given that both models generate different moments for individual variables during crisis. Our result demonstrates the robustness of the BGG model in terms of the parameter invariance problem, making the BGG model a reasonable tool to evaluate the consequences of alternative policies, in the sense of Lucas (1976). One possible downside of this finding, from the policymaker's perspective, could be that there is no chance to learn about the misspecification in the approximating model through the estimated parameters. In other words, the policymaker does not have any motivation to improve upon its own approximating model, which could potentially be costly in terms of stabilizing the economy.

3.2 Type 1 Cost: Stabilization of the Model Economy

In this and the following subsection, we examine whether the misspecification leads to poor performance of the monetary policy in the context of stabilizing the economy. First, we check whether the optimal monetary policy rule suggested by the BGG model ("BGG-optimal policy rule") is helpful in stabilizing the economy in the (unknown) GK model economy.

Table 4 shows how the standard deviation of selected variables and the associated welfare loss change across all four periods. In the crisis period, we confirm that the welfare loss rises to 1.5099, or by 12.0%, compared to its 1.3486 in the pre-crisis period. In the policy shift period, the welfare loss *further* rises to 1.5335, or by 1.6%, compared to the 1.5099 in the crisis period. This means that the policymaker unintentionally destabilizes the economy through its use of a misspecified model, but the magnitude of destabilization caused by the policy is smaller than the destabilization caused by the crisis.

Table 4 further provides us additional information about the nature of the destabilization. First, it shows that the overall rise in the welfare loss is driven by the increase in the standard deviation of output (from 3.42 to 3.57), which dominates the marginal reduction in the standard deviations of inflation and the interest rate. Second, in the post-crisis period, the welfare loss falls to 1.3744, which is 1.9% higher than that of the pre-crisis period (1.3486). This is because the standard deviation of output, which increased during the crisis, has not returned to the pre-crisis level.

The further destabilization of the economy through adopting the BGG-optimal policy rule may have been caused by two factors: one is through the use of a model that badly approximates reality, and the other is through the choice of model parameters that are biased in relation to the "true" values. To better understand which of the two is responsible for our outcome, we repeat the same exercise assuming that the policymaker is informed about the true parameter values in all periods. Results are shown in the Appendix Table A.4. We find that the welfare loss becomes even higher than the baseline result, suggesting that the adverse outcome is due to the policymaker using a misspecified model to design its policy, not because the model parameters fail to stay invariant.

3.3 Type 2 Cost: Opportunity Cost of Using the Misspecified Model

The next question is how the policymaker would have performed if he had been equipped with the correctly specified model and how the BGG-optimal policy rule would fare against the policy generated from a correctly-specified model.

Table 5 reports the policy parameters selected during the policy shift period and the resulting welfare loss observed in the data-generating GK model for both the policy shift and the post-crisis periods. We show that by using the GK model, the policymaker can lower the welfare loss by 10.0% compared to the BGG-optimal policy rule (1.5335 to 1.3799, see Column (1)). This magnitude seems economically significant, because the welfare loss comes down to a level only slightly higher than the pre-crisis period (i.e., 1.3486). To achieve the same reduction in the level of loss under the GK model, the policymaker would have to reduce the standard deviation of inflation by 14.1% (0.76 to 0.65), output by 14.4% (3.42 to 2.93), or interest rate by 23.1% (1.25 to 0.97) while keeping other standard deviations fixed. This appears to be a difficult task, given that the only policy option is the conventional interest rate rule in the BGG model.

There are two possible reasons for the BGG-optimal policy rule to perform worse than the GK-optimal policy rule. One is because the policymaker uses a misspecified model in choosing the optimal interest rate policy. The other is because public financial intermediation cannot be used in the BGG model. To investigate this point, we examine a case in which the policymaker is equipped with the correctly specified GK model, but public financial intermediation is not feasible ($\nu_g = 0$). Results are shown in column (2) of Table 5. The welfare loss under the constrained GK-optimal policy rule with $\nu_g = 0$ would be smaller than in the BGG-optimal policy rule (1.5053, as opposed to 1.5335), but the magnitude of improvement remains much milder compared to the outcome under the baseline GK-optimal policy rule (-1.8%, as opposed to -10.0%). This exercise shows that public financial intermediation (or the lack of it) plays a key role in stabilizing the economy during the crisis.

The performance of different policies in the post-crisis period is shown in the last row of Table 5. The welfare losses are found to be very similar across policies. For example, the BGG-optimal policy rule performs only marginally worse than the constrained GK-optimal policy rule (ν_g set to zero) and does slightly better than the baseline GK-optimal policy rule ($\nu_g = -3.08$). This result shows that the BGG-optimal policy rule performs robustly once the economy returns to the pre-crisis state. It also shows that the optimal intensity of public financial intermediation (ν_g) is sensitive to the credit channel-related parameters.

4 Can Policymakers be "Nudged" Toward a Better Policy?

So far we have maintained the assumption that the policymaker, who is equipped with the BGG model, is confined to the conventional Taylor rule that minimizes the quadratic welfare loss of the form suggested by Woodford (2003). In this section, we consider two alternative policy options that are feasible under the BGG model and examine whether they can be used to improve the outcome.

4.1 Expanding the List of Variables in the Monetary Policy Rule

The first experiment is to allow the policymaker to adjust the interest rate in response to credit channel variables. The benefit of using a monetary policy rule with additional credit channel-related variables has been studied extensively in the literature. There is also narrative evidence that in the early stage of the financial crisis, the Fed had aggressively lowered the federal funds rate by taking into account the deterioration of the financial market. Guided by such observations, we consider the following "expanded" Taylor rule

$$R_t = R_{t-1}^{\rho_R} \left[(\Pi_t)^{\phi_\pi} (X_t)^{\phi_X} \left(\frac{X_t}{X_{t-1}} \right)^{\phi_{\Delta X}} (CC_t)^{\nu_{CC}} \right]^{1-\rho_R} \exp\left(S_{mp,t}\right), \tag{13}$$

where CC is a credit channel-related variable, and ν_{CC} is the associated reaction coefficient that the policymaker can freely choose. We consider two candidate variables (risk spread, leverage) with three timing options (contemporaneous, one period lagged, and one period ahead).

Table 6 shows the welfare loss during the policy shift period using the expanded Taylor rule in the Equation (13). All policy rules result in a lower welfare loss (between 1.4878 and 1.5130) compared to the baseline BGG-optimal policy rule with $\nu_{CC} = 0$ (i.e., 1.5335). Also, in four of the six cases the loss under the new policy rule becomes lower than the loss observed in the crisis period (i.e., 1.5099). When we compare the magnitude of the reduction across different credit channel variables, we find that specifications with the risk spread lead to larger reductions in loss (between -2.1% and -3.0%) compared to the cases with leverage ratio (between -1.4% and -1.6%). In addition, we find that the one period lagged variables always perform better than other timings.

Our result is in line with many of the previous studies (e.g., Curdia and Woodford, 2015) that find that adding credit channel variables into the Taylor rule improves the outcome when the true data-generating process involves a credit channel. The result adds to the literature that such a modification is effective in overcoming the stabilization bias caused by model misspecification.

4.2 Assigning Alternative Stabilization Objectives

The second possible solution is to assign alternative stabilization objectives that the policymaker should consider in the quadratic loss function. In the monetary policy literature, researchers have long discussed whether society is better off if the policymaker were assigned an objective different from the social welfare function. A classic example is provided by Rogoff (1985), who shows analytically that a "conservative" central banker with a strong preference towards inflation stabilization *beyond* the socially desired level may achieve a better outcome.[24] Alternatively, researchers have argued that when the model features additional structures and frictions, an additional component appearing in

[24] In Rogoff's case, the adjustments in the preference are motivated by the unobservable shock process that affects the time-consistent level of inflation and the trade-off between inflation and employment stabilization objectives. Also see Canzoneri *et al.* (1997), Herrendorf and Lockwood (1997), King (1997) for related works.

the quadratic loss function can be justified from a welfare-theoretic ground.[25] In contrast, our purpose here is to examine whether the same type of adjustment in the stabilization objectives would be useful to prevent the destabilization of the economy that is caused by model misspecification.

We now assume that the monetary policymaker chooses his policy parameters based on an "expanded" quadratic welfare loss measure (7), where the vector Γ includes a fourth variable in addition to inflation, output, and interest rate. For the candidate variable, we consider ten endogenous variables (consumption, investment, capital, hours worked, wage rate, risk spread, asset price, leverage, and rental rate of capital), which are all observable in the BGG model. Figure 1 shows the realized welfare loss in the data-generating model for four of the ten variables. Relative to the baseline case with the BGG-optimal policy rule (i.e., 1.5335), the loss is reduced when consumption (1.5158), hours worked (1.5058), wage rate (1.5241), and capital (1.5264) were individually added. However, in the single case of hours worked, the resulting loss becomes lower than in the crisis period (i.e., 1.5099). For the other six variables not included in the figure, assigning a positive weight leads to a *larger* loss.

Figure 2 shows the welfare loss when *two* weights are simultaneously changed. In all cases, the resulting loss is lower than the crisis period (1.5099), effectively avoiding further destabilization of the economy through policy shift.[26] The best outcome is achieved with $\lambda_L = 0.06$ and $\lambda_R = 0.266$, with the resulting loss being 1.5054. But even in this case the welfare loss remains notably higher than the loss under the GK-optimal policy rule that allows for public financial intermediation (i.e., 1.3799).

5 Conclusion

This paper examines the consequences of model misspecification in the credit channel model when a misspecification occurs in the *type* of credit market friction. In particular,

[25] See, for example, De Paoli (2009) and Erceg *et al.* (2000).

[26] We have also tried other combinations of variables, but none of them led to a notable reduction in the loss measure.

we choose the credit channel model of Gertler and Karadi (2010) to represent the unknown reality and the model of Bernanke *et al.* (1999) as the approximating model with which the monetary policymaker is equipped. Our main finding is that while the use of Bernanke *et al.*'s (1999) model leads to a destabilization of the model economy, the change in the welfare loss measure remains quantitatively minor relative to the opportunity cost of using the misspecified model. We find that many of the gains of using the correctly-specified model come from public financial intermediation, which indirectly supports the current practice of explicitly modeling the balance sheet constraint. We further show that adding credit channel variables in the Taylor rule or assigning alternative stabilization objectives to the policymaker can mitigate the problem of using a misspecified model, a point which has not been explored much in the relevant literature.

Our findings provide a new perspective to what the literature has long recognized as the parameter invariance problem associated with DSGE models. We show in our paper that despite the difference in how the credit market friction is modeled across the two models, the estimated parameters themselves do not tell us much. While our paper shows that the approximating model performs robustly in terms of model parameter estimation, ironically it also makes it difficult for the policymaker to infer the "true" structure of the economy.

One of the potential weaknesses of our experiment is that it does not consider the zero lower bound (ZLB) problem, which could significantly increase the cost of model misspecification because of the restrictions imposed on conventional interest rate policy. Studies such as Williams (2009) report that the welfare cost of ZLB has been large during the recent financial crisis. Del Negro *et al.* (2016) further demonstrate that when ZLB is binding, a liquidity shock can have a large effect on the aggregate economy.

An interesting venue to explore in future studies is adding more structure to both the data-generating and the approximating models so that a wider variety of policy options can be considered. For example, by assuming that extending credit involves additional resource cost, one can think of government subsidies that may potentially correct for the undersupply of loans (Christiano and Ikeda, 2013). Another possible extension is the introduction of new financial shocks other than what we considered in this paper. While the discussion regarding what type of financial shock best explains the recent financial crisis is far from reaching consensus,[27] it would surely be interesting to see whether the presence of different shock(s) would make any difference in the context of monetary policymaking.

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Appendix A: Full Model Description

We start with describing the part that is common to both credit channel models (section A.1). The common part largely follows the specification in Justiniano *et al.* (2010, JPT) and Gali *et al.* (2012). Details about the Bernanke *et al.* (1999, BGG)'s model is shown in section A.2 and details of the Gertler and Karadi (2011, GK)'s model is shown in section A.3.

A.1.1 Household

Each household $k \in [0, 1]$ maximize its lifetime utility,

$$\max E_t \sum\nolimits_{j=0}^{\infty} \beta^j \exp(b_{t+j}) \left[\log(C_{t+j} - hC_{t+j-1}) - \varphi \frac{L_{t+j}(k)^{1+\psi}}{1+\psi} \right],$$

where C_t is consumption, L_t is labor supply, β is the quarterly discount factor. h is the consumption habit parameter, ψ is the inverse Frisch elasticity, and φ is the utility weight on leisure which pins down the steady-state labor in the model. b_t is a preference shock modeled as[28]

$$b_t = (b_{t-1})^{\rho_b} \exp(e_{b,t}),$$

$$e_{b,t} \sim N(0, \sigma_b^2).$$

The budget constraint for the household is

$$P_t C_t + P_t I_t + T_t + D_t = R_{t-1} D_{t-1} + prof_t + W_t(k) L_t(k)$$

where P_t is price level, I_t is investment, T_t is lump-sum taxes, D_t is deposit, R_t is the gross interest rate on deposits, $prof_t$ is the profit from owing firms, W_t is the wage rate.

A.1.2 Goods producers

[28]Note that in actual estimation, we follow the suggestion by JPT and normalize the (linearized) preference shock as follows: $\widehat{b}_t = \left(\frac{(1-\rho_b)(1-h\beta\rho_b)(1-h)}{1+h+h^2} \right) (b_t - \bar{b})$. Similar normalization is applied to price mark-up shock and wage mark-up shock (defined later).

There are two types of goods producing firms. Final good producers aggregate the intermediate goods into a composite final good as,

$$Y_t = \left(\int_0^1 Y_t(z)^{\frac{1}{1+\lambda_{p,t}}} dz \right)^{1+\lambda_{p,t}},$$

where $Y_t(z)$ is the total production of intermediate goods of firm $z \in [0,1]$. $\lambda_{p,t}$ is the price markup shock modeled as

$$1 + \lambda_{p,t} = (1+\lambda_p)^{1-\rho_p} (1+\lambda_{p,t-1})^{\rho_p} \exp\left(e_{p,t} - \theta_p e_{p,t-1}\right),$$

$$e_{p,t} \sim N(0, \sigma_p^2).$$

Intermediate goods producers hire labor and capital through the factor markets. These inputs are used to produce intermediate output,

$$Y_t(z) = \max\left[A_t K_t^{\alpha}(z) L_t^{1-\alpha}(z) - A_t F; 0\right],$$

where α is the capital share of income and F is the fixed cost of production. A_t is the technology shock that is modeled as

$$A_t = (A_{t-1})^{\rho_a} \exp\left(e_{a,t}\right), \tag{14}$$

$$e_{a,t} \sim N(0, \sigma_a^2)$$

The overall price is determined as a geometric average of the prices for adjusters and non-adjusters

$$P_t = \left[(1-\xi_p)\left(\tilde{P}_t\right)^{\frac{1}{\lambda_{p,t}}} + \xi_p \left(\pi^{1-\iota_p} \pi_{t-1}^{\iota_p} P_{t-1}\right)^{\frac{1}{\lambda_{p,t}}} \right]^{\lambda_{p,t}},$$

where $\tilde{P}_t$ is the price chosen by the adjusters and π_t is inflation. ξ_p is the Calvo price parameter, ι_p is the price indexation parameter. $\lambda_{p,t}$ is the price markup shock modeled as[29]

$$1 + \lambda_{p,t} = (1+\lambda_p)^{1-\rho_p} (1+\lambda_{p,t-1})^{\rho_p} \exp\left(e_{p,t} - \theta_p e_{p,t-1}\right),$$

$$e_{p,t} \sim N(0, \sigma_p^2).$$

[29] Note that in actual estimation, we normalize the (linearized) price markup shock as follows: $\widehat{\lambda}_{p.t} = \left(\frac{(1-\xi_p\beta)(1-\xi_p)}{\xi_p(1+\iota_p\beta)}\right)(\log(1+\lambda_{p,t}) - \log(1+\overline{\lambda}_p)$.

Price adjuster z maximize the following objective,

$$\max E_t \sum\nolimits_{j=0}^{\infty} \xi_p^j \beta^j \frac{\Lambda_{t+j}}{\Lambda_t} \left[P_t(z) \left(\prod\nolimits_{l=0}^{j} \pi^{1-\iota_p} \pi_{t+l-1}^{\iota_p} \right) Y_{t+j}(z) - W_{t+j} L_{t+j}(z) - MPK_{t+j} K_{t+j}(z) \right],$$

where Λ_t is the marginal utility of nominal income for the representative household, and MPK_t is the marginal product of capital. Price non-adjuster z follows the indexation rule,

$$P_t(z) = \pi^{1-\iota_p} P_{t-1}(z) \pi_{t-1}^{\iota_p}.$$

A.1.3 Capital market

Demand for capital is determined through the cost minimization problem of the intermediate goods firms,

$$MPK_t = MC_t(z) A_t^{1-\alpha} \left(\frac{L_t(z)}{K_t(z)} \right)^{1-\alpha},$$

where $MC_t(z)$ is the marginal cost.

Supply for capital is determined through solving the optimal choice of investment by the capital owner. The value of physical capital can be expressed as,

$$\Phi_t = \beta E_t \Lambda_{t+1} MPK_{net,t} + (1-\delta) \beta E_t \Phi_{t+1},$$

where δ is the depreciation rate of capital. $MPK_{net,t}$ is the marginal product of capital net of capital utilization cost,

$$MPK_{net,t} = MPK_t u_t - P_t a(u_t),$$

where $a(u_t)$ is the cost of capital utilization per unit of physical capital in real terms. u_t is the capital utilization rate, which determines the amount of effective capital available for production in period t,

$$K_t = u_t \overline{K}_{t-1}.$$

Physical capital accumulates according to the following law of motions

$$\overline{K}_t = (1-\delta) \overline{K}_{t-1} + \mu_t \left(1 - S\left(\frac{I_t}{I_{t-1}} \right) \right) I_t$$

where S represents the adjustment cost of capital that satisfies $S = S' = 0$ and $S'' > 0$ in the steady state. μ_t is a marginal efficiency of investment (MEI) shock modeled as

$$\mu_t = (\mu_{t-1})^{\rho_\mu} \exp\left(e_{\mu,t}\right),$$

$$e_{\mu,t} \sim N(0, \sigma_\mu^2).$$

Finally, gross rate of return on holding capital is,

$$E_t R_{t+1}^k = E_t \left[\frac{MPK_{t+1} + (1-\delta)\, Q_{t+1}}{Q_t} \right] \exp\left(S_{rp,t}\right),$$

where $Q_t = \Phi_t / P_t \Lambda_t$ is the Tobin's q. $S_{rp,t}$ is the risk premium shock modeled as,

$$S_{rp,t} = (S_{rp,t-1})^{\rho_{rp}} \exp\left(e_{rp,t}\right),$$

$$e_{rp,t} \sim N(0, \sigma_{rp}^2).$$

A.1.4 Labor market

Demand for labor is determined through the cost minimization problem of the intermediate goods firms,

$$W_t = MC_t(z) A_t^{1-\alpha} \left(\frac{L_t(z)}{K_t(z)} \right)^{-\alpha},$$

where $MC_t(z)$ is the marginal cost.

Supply for labor is determined by the employment agency, who aggregates the household labor into a homogeneous labor input as,

$$L_t = \left(\int_0^1 L_t(k)^{\frac{1}{1+\lambda_{w,t}}} dk \right)^{1+\lambda_{w,t}},$$

where $\lambda_{w,t}$ is the wage markup shock modeled as,[30]

$$1 + \lambda_{w,t} = (1+\lambda_w)^{1-\rho_w} (1+\lambda_{w,t-1})^{\rho_w} \exp\left(e_{w,t} - \theta_w e_{w,t-1}\right),$$

$$e_{w,t} \sim N(0, \sigma_w^2).$$

[30] Note that in actual estimation, we normalize the (linearized) wage markup shock as follows: $\widehat{\lambda}_{w.t} = \left(\frac{(1-\xi_w\beta)(1-\xi_w)}{\xi_w(1+\beta)\left(1+\psi(1+\frac{1}{\overline{\lambda}_w})\right)} \right) (\log(1+\lambda_{w,t}) - \log(1+\overline{\lambda}_w)$.

The overall wage is determined as a geometric average of wages for adjusters and non-adjusters

$$W_t = \left[(1 - \xi_w) \left(\tilde{W}_t \right)^{\frac{1}{\lambda_{w,t}}} + \xi_w \left(\pi^{1-\iota_w} \pi_{t-1}^{\iota_w} W_{t-1} \right)^{\frac{1}{\lambda_{w,t}}} \right]^{\lambda_{w,t}},$$

where $\tilde{W}_t$ is the wage rate chosen by the adjusters and π_t is inflation. ξ_w is the Calvo wage parameter, ι_w is the wage indexation parameter. Wage adjuster k maximize the following objective,

$$\max E_t \sum\nolimits_{j=0}^{\infty} \xi_w^j \beta^j \left[\exp(-b_{t+j}) \varphi \frac{L_{t+j}(k)^{1+\psi}}{1+\psi} + \Lambda_{t+j} W_t(k) L_{t+j}(k) \right],$$

Wage non-adjuster k follows the indexation rule,

$$W_t(k) = \pi^{1-\iota_w} W_{t-1}(k) \pi_{t-1}^{\iota_w}.$$

A.1.5 Government

In both models, government spending is modeled as a fraction of the final goods produced in the economy,

$$G_t = \left(1 - \frac{1}{g_t} \right) Y_t,$$

where g_t is the government spending shock modeled as,

$$g_t = (g_{t-1})^{\rho_g} \exp\left(e_{g,t}\right),$$

$$e_{g,t} \sim N(0, \sigma_g^2).$$

In the BGG model, government spending is financed as,

$$G_t + D_{g,t} = T_t + R_{t-1} D_{g,t-1},$$

where $D_{g,t}$ is the government deposit that yields the gross interest rate R_t and T_t is the lump-sum taxes. In the GK model, government spending is financed as,

$$G_t + C_t^{fi} + D_{g,t} = T_t + R_{t-1} D_{g,t-1} + R_t^k Q_t \overline{K}_{g,t-1},$$

where C_t^{fi} is the efficiency cost of public financial intermediation and $Q_t\overline{K}_{g,t-1}$ is the value of public financial intermediation.

In both models, the interest rate is set according to the Taylor rule,

$$R_t = R_{t-1}^{\rho_R}\left[(\Pi_t)^{\phi_\pi}(X_t)^{\phi_X}\left(\frac{X_t}{X_{t-1}}\right)^{\phi_{\Delta X}}\right]^{1-\rho_R}\exp\left(S_{mp,t}\right),$$

where $S_{mp,t}$ is the monetary policy shock modeled as

$$S_{mp,t} = (S_{mp,t-1})^{\rho_{mp}}\exp\left(e_{mp,t}\right),$$

$$e_{mp,t} \sim N(0, \sigma_{mp}^2).$$

A.1.6 Goods market equilibrium

In the BGG model, the goods market equilibrium satisfies the following resource constraint,

$$Y_t = C_t + I_t + G_t + C_t^b + a(u_t),$$

where C_t^b is the consumption of borrowers that exit the market. In the GK model, the goods market equilibrium satisfies,

$$Y_t = C_t + I_t + G_t + C_t^{fi} + a(u_t).$$

In both models output (=GDP) is defined as,

$$X_t = Y_t - a(u_t).$$

A.2.1 Financial market in the BGG model

In the BGG model, the borrower m's objective is to maximize the expected profit in the next period that can be generated through capital investment. When financing the investment, the borrower is allowed to obtain funds from the (representative) lender. Thus the borrower m's balance sheet at period t is expressed as

$$Q_t\overline{K}_{t-1}(m) = N_t(m) + B_t(m),$$

where $Q_t\overline{K}_{t-1}(m)$ is the asset value at the beginning of period t and $N_t(m)$ is the beginning of period net worth, and $B_t(m)$ is the funds acquired from the lender. The objective function for the borrower can be expressed as

$$V_t(m) = \max \Gamma^b E_t \left[R^k_{t+1} Q_{t+1} \overline{K}_t(m) \right],$$

where $R^k_{t+1} Q_{t+1} \overline{K}_t(m)$ is the overall profit from capital investment and Γ^b is the fraction of profit that will be kept by the borrower after sharing the profit with the lender.

The lender is willing to provide the necessary funds as long as the net revenue from lending covers the opportunity cost of investing the funds into a risk-free asset. The condition is satisfied when

$$\Gamma^l E_t \left[R^k_{t+1} Q_{t+1} \overline{K}_t(m) \right] = R_t B_t,$$

where Γ^l is the fraction of profit kept by the lender.

The BGG model assumes that the individual borrower faces an idiosyncratic productivity shock ω_b that makes the profit per unit of capital investment potentially differ across borrowers. The shock follows the log-normal distribution with a mean of $-0.5\sigma_b^2$ and variance of σ_b^2 such that $E(\omega_b) = 1$. In order for the representative lender to gain access to the realized ω_b he is forced to pay a bankruptcy cost μ_b that is proportional to the asset value. To guarantee that the lender is guarded against the shock, the contract pre-specifies a cutoff value for the productivity shock $\overline{\omega}_b$ such that if the realized shock falls short of the cutoff value, the borrower is going to seize the residual claims net of the bankruptcy cost. Solving the optimal contract problem and aggregating across all borrowers leads to an expression that contemporaneously relates the nationwide leverage ratio of the borrower to the premium on external funds

$$E_t R^k_{t+1} = \left(\frac{Q_t \overline{K}_t}{N_{t+1}} \right)^{\nu} R_t,$$

where ν is the positive credit market friction parameter, which is determined through the choice of μ_b, σ_b.

A.2.2 Net worth dynamics in the BGG model

Aggregate net worth of the borrower is defined as the sum of the net worth for the surviving borrowers and their labor income

$$N_{t+1} = \gamma_{BGG}\left[R_t^k Q_{t-1}\overline{K}_{t-1} - \left(R_{t-1} + \frac{AC_{t-1}}{Q_{t-1}\overline{K}_{t-1} - N_t}\right)\left(Q_{t-1}\overline{K}_{t-1} - N_t\right)\right] + W_{b,t}L_b,$$

where $W_{b,t}$ is the borrower's wage rate, L_b is the (fixed) labor supply, and γ_{BGG} is the survival rate of the borrower. AC_{t-1} is the size of bankruptcy cost incurred in period $t-1$, which is determined as

$$AC_{t-1} = \mu_b \int_0^{\overline{\omega}_{b,t}} \omega_b R_t^k Q_{t-1}\overline{K}_{t-1} d\omega_b.$$

Borrowers who fail to survive consume the following amount before exiting the market

$$C_t^b = (1-\gamma_{BGG})\left[R_t^k Q_{t-1}\overline{K}_{t-1} - \left(R_{t-1} + \frac{AC_{t-1}}{Q_{t-1}\overline{K}_{t-1} - N_t}\right)\left(Q_{t-1}\overline{K}_{t-1} - N_t\right)\right].$$

A.3.1 Financial market in the GK model

In GK model, the borrower m's objective is to maximize the expected lifetime net worth,

$$V_t(m) = \max E_t \sum\nolimits_{j=0}^{\infty} (1-\gamma_{GK})\gamma_{GK}^j (\beta^{j+1}\Upsilon_{t,t+j+1}) N_{t+j}(m),$$

where γ_{GK} is the survival rate of the borrower, $\beta^j \Upsilon_{t,t+j}$ is the stochastic discount factor that applies to period $t+j$ earnings. Beginning of period net worth N_{t+1} is defined as the sum of excess return from capital investment and the (return-adjusted) net worth from the previous period,

$$N_{t+1}(m) = (R_{t+1}^k - R_t)Q_t\overline{K}_{t-1}(m) + R_t N_t(m).$$

The above objective function can be rewritten in recursive form as

$$V_t(m) = v_t Q_t \overline{K}_{t-1}(m) + \eta_t N_t(m),$$

where

$$v_t = E_t\left[(1-\gamma_{GK})(\beta\Upsilon_{t,t+1})(R_{t+1}^k - R_t) + \gamma_{GK}(\beta\Upsilon_{t,t+1})\frac{Q_{t+1}\overline{K}_t(m)}{Q_t\overline{K}_{t-1}(m)} v_{t+1}\right],$$

$$\eta_t = E_t\left[(1-\gamma_{GK}) + \gamma_{GK}(\beta\Upsilon_{t,t+1})\frac{N_{t+1}(m)}{N_t(m)}\eta_{t+1}\right].$$

As in the BGG model, the borrower is allowed to obtain funds from the (representative) lender to finance its capital investment. The lender is willing to provide funds as long as the terminal value of net worth at a given period is greater than or equal to the fund that can be appropriated by the borrower,

$$V_t(m) \geq \lambda Q_t \overline{K}_{t-1}(m),$$

where λ is the fraction of asset that can be diverted by the borrower. When this incentive constraint is binding, the common "threshold" leverage that applies to all borrowers can be expressed as

$$\phi_t = \frac{\eta_t}{\lambda - \upsilon_t}.$$

A.3.2 Net worth dynamics in the GK model

Aggregate net worth of the borrower is defined as the sum of net worth for the surviving borrowers and for the entering borrowers

$$N_t = N_{e,t} + N_{n,t}.$$

The net worth for the surviving borrowers is

$$N_{e,t+1} = \gamma_{GK}[(R_t^k - R_{t-1})\phi_{t-1} + R_{t-1}]N_t,$$

whereas the net worth for the entering borrowers is

$$N_{n,t+1} = \omega Q_t \overline{K}_{t-1},$$

where ω is the proportional transfer from the lender to the entering borrowers. Thus the overall net worth of the borrower grows as follows,

$$N_{t+1} = \gamma_{GK}[(R_t^k - R_{t-1})\phi_{t-1} + R_{t-1}]N_t + \omega Q_t \overline{K}_{t-1}.$$

A.3.3 Monetary policy in the GK model

In the GK model, the monetary policymaker can engage in public financial intermediation in addition to the conventional interest rate policy that is also available in the BGG model. The total value of financial intermediation is defined as the sum of private financial intermediation and the public financial intermediation

$$Q_t\overline{K}_{t-1} = Q_t\overline{K}_{p,t-1} + Q_t\overline{K}_{g,t-1}.$$

The fraction of public financial intermediation is defined as

$$\psi_{g,t} \equiv \frac{Q_t\overline{K}_{g,t-1}}{Q_t\overline{K}_{t-1}},$$

and it is endogenously determined through the following feedback rule,

$$\psi_{g,t} = \psi_g \phi_t^{\nu_g},$$

where ν_g represents the degree of intervention. When public financial intermediation is implemented, an additional expenditure arises that captures the efficiency cost associated with implementing the policy

$$C_t^{fi} = \tau\psi_{g,t}Q_t\overline{K}_{t-1},$$

where τ is the (unit) efficiency cost of public financial intermediation.

Table A.1: Forecast Error Variance Decomposition

	(1) Demand shock	(2) Supply shock	(3) Risk prem.shock
Pre-crisis period			
Inflation Π	24.7%	75.3%	0.1%
Output X	45.1%	54.7%	0.2%
Interest rate R	96.9%	2.7%	0.4%
Crisis period			
Inflation Π	27.8%	71.4%	0.9%
Output X	48.9%	48.6%	2.6%
Interest rate R	93.1%	2.3%	4.5%

Note: demand shock is defined as the sum of monetary policy shock, government spending shock, marginal efficiency of investment shock, and preference shock. Supply shock is defined as the sum of price markup shock, wage markup shock, and technology shock.

Table A.2: Change in Volatility from Pre-Crisis to Crisis

	(1) Pre-crisis	(2) Crisis	(3) Change
GK model			
Inflation σ_Π	0.73	0.76	+4.3%
Output σ_X	3.29	3.42	+3.9%
Interest rate σ_R	1.12	1.25	+11.6%
Welfare loss L_0	1.3486	1.5099	+12.0%
BGG model			
Inflation σ_Π	0.79	0.83	+5.4%
Output σ_X	3.65	3.88	+6.3%
Interest rate σ_R	1.29	1.35	+5.0%
Welfare loss L_0	1.6502	1.8414	+11.6%

Table A.3: Pseudo-true Values, JPT Model

	Subsample			
	(1) Pre-Crisis	(2) Crisis	(3) Policy-Shift	(4) Post-Crisis
Preference / technology parameters				
Consumption habit h	0.84 (0.01)	0.85 (0.01)	0.86 (0.00)	0.86 (0.00)
Inverse Frisch elasticity ψ	4.54 (0.38)	5.27 (0.47)	5.22 (0.46)	5.00 (0.09)
Elast. of capital utilization cost χ	6.22 (0.57)	6.93 (0.70)	6.64 (0.64)	6.15 (0.55)
Investment adjustment cost S''	1.15 (0.05)	1.14 (0.05)	1.11 (0.05)	0.99 (0.04)
Calvo prices ξ_p	0.85 (0.00)	0.84 (0.00)	0.86 (0.00)	0.84 (0.00)
Price indexation ι_p	0.28 (0.02)	0.25 (0.01)	0.24 (0.01)	0.24 (0.01)
Calvo wages ξ_w	0.69 (0.01)	0.69 (0.01)	0.69 (0.01)	0.69 (0.01)
Wage indexation ι_w	0.13 (0.02)	0.11 (0.02)	0.10 (0.02)	0.10 (0.02)
Shock-related parameters				
Persistence: mon. pol. shock ρ_{mp}	0.15 (0.01)	0.13 (0.01)	0.13 (0.01)	0.13 (0.01)
Persistence: tech. shock ρ_A	0.99 (0.00)	0.99 (0.00)	0.99 (0.00)	0.99 (0.00)
Persistence: gov. shock ρ_G	0.99 (0.00)	0.99 (0.00)	0.99 (0.00)	0.99 (0.00)
Persistence: MEI shock ρ_μ	0.71 (0.01)	0.74 (0.01)	0.74 (0.01)	0.70 (0.01)
Persistence: Price markup shock ρ_p	0.95 (0.00)	0.95 (0.01)	0.95 (0.00)	0.95 (0.00)
Persistence: Wage markup shock ρ_w	0.97 (0.00)	0.97 (0.00)	0.97 (0.00)	0.97 (0.00)
Persistence: Preference shock ρ_b	0.62 (0.01)	0.62 (0.01)	0.61 (0.01)	0.58 (0.01)
MA parameter: Price markup shock θ_p	0.80 (0.01)	0.79 (0.01)	0.79 (0.01)	0.79 (0.01)
MA parameter: Wage markup shock θ_w	0.91 (0.00)	0.91 (0.00)	0.90 (0.00)	0.91 (0.00)

Table A.3: Pseudo-true Values, JPT Model (continued)

	Subsample			
	(1) Pre-Crisis	(2) Crisis	(3) Policy-Shift	(4) Post-Crisis
Size: Monetary policy shock σ_m	0.22 (0.00)	0.22 (0.00)	0.22 (0.00)	0.22 (0.00)
Size: Technology shock σ_A	0.89 (0.01)	0.89 (0.01)	0.89 (0.01)	0.89 (0.01)
Size: Government spending shock σ_G	0.35 (0.00)	0.35 (0.00)	0.35 (0.00)	0.35 (0.00)
Size: MEI shock σ_μ	2.70 (0.07)	3.30 (0.08)	3.28 (0.08)	2.48 (0.05)
Size: Price markup shock σ_{p*}	0.14 (0.00)	0.14 (0.00)	0.14 (0.00)	0.14 (0.00)
Size: Wage markup shock σ_{w*}	0.20 (0.00)	0.20 (0.00)	0.20 (0.00)	0.20 (0.00)
Size: Preference shock σ_{b*}	0.05 (0.00)	0.04 (0.00)	0.04 (0.00)	0.05 (0.00)

Table A.4: Standard Deviation under Correct Parameter Values

	Subsample			
	(1) Pre-Crisis	(2) Crisis	(3) Policy-Shift	(4) Post-Crisis
Inflation σ_π	0.73	0.76	0.73	0.70
Output σ_X	3.29	3.42	3.82	3.68
Interest rate σ_R	1.12	1.25	1.16	1.03
Welfare loss L_0	1.3486	1.5099	1.5488	1.3842

Table 1: Estimated Parameters

	Parameter value	Distri-bution	Standard deviation
Consumption habit h	0.78	Beta	0.04
Inverse Frisch elasticity ψ	3.79	Gamma	0.76
Elast.of capital utilization cost χ	5.30	Gamma	1.01
Investment adjustment cost S''	2.85	Gamma	0.54
Calvo prices ξ_p	0.84	Beta	0.02
Price indexation ι_p	0.24	Beta	0.08
Calvo wages ξ_w	0.70	Beta	0.05
Wage indexation ι_w	0.11	Beta	0.03
Persistence of monetary policy shock ρ_{mp}	0.14	Beta	0.06
Persistence of technology shock ρ_A	0.99	Beta	0.01
Persistence of government spending shock ρ_G	0.99	Beta	0.01
Persistence of MEI shock ρ_μ	0.72	Beta	0.04
Persistence of price markup shock ρ_p	0.94	Beta	0.02
Persistence of wage markup shock ρ_w	0.97	Beta	0.01
Persistence of preference shock ρ_b	0.67	Beta	0.04
Persistence of risk premium shock ρ_{rp}	0.50	Beta	0.04
MA parameter of price markup shock θ_p	0.77	Beta	0.07
MA parameter of wage markup shock θ_w	0.91	Beta	0.02
Size of monetary policy shock $100\sigma_{mp}$	0.22	Inv-Gamma	inf
Size of technology shock $100\sigma_A$	0.88	Inv-Gamma	inf
Size of government spending shock $100\sigma_G$	0.35	Inv-Gamma	inf
Size of MEI shock $100\sigma_\mu$	6.03	Inv-Gamma	inf
Size of price markup shock $100\sigma_{p*}$	0.14	Inv-Gamma	inf
Size of wage markup shock $100\sigma_{w*}$	0.20	Inv-Gamma	inf
Size of preference shock $100\sigma_{b*}$	0.04	Inv-Gamma	inf
Size of risk premium shock $100\sigma_{rp}$			
Pre-crisis	0.20	Inv-Gamma	inf
Crisis	1.00	Inv-Gamma	inf

Note: Parameter values in the second column are used in both the data-generating model and as the prior mean used in estimating the parameters in the approximating model. All model parameters are based on quarterly frequency.

Table 2: Non-estimated Parameters

(a) *Parameters Common to Both Models*		
Discount factor β		0.9904
Capital share α		0.17
SS Price Markup $_{p}ss$		0.23
SS Wage Markup $_{w}ss$		0.15
SS Work Hours (in log) $logLss$		0.38
Government spending share of output $\overline{G}/\overline{X}$		0.21
Depreciation rate δ		0.025

(b) *GK Model Related Parameters*		
Fraction of asset that can be diverted λ		
	Pre-crisis	0.3503
	Crisis	0.5130
Proportional transfer to the entering borrowers ω		
	Pre-crisis	0.0013
	Crisis	0.0010
Survival probability of lender γ_{GK}		0.9724
SS government share of financial intermediation ψ		0.07
Efficiency cost of public financial intermediation τ		0.001

(c) *BGG Model Related Parameters*		
Uncertainty about firm's investment project σ_b		
	Pre-crisis	0.093
	Crisis	0.129
Bankruptcy cost μ_b		
	Pre-crisis	0.039
	Crisis	0.043
Survival probability of lender γ_{BGG}		0.9724
Borrower spending share of output $\overline{C^e}/\overline{Y}$		0.01

(d) *Policy Related Parameters*		
Taylor rule: Inflation ϕ_π		4.06
Taylor rule: Output ϕ_X		-0.52
Taylor rule: Output Growth $\phi_{\Delta X}$		10.45
Interest rate smoothing ρ_R		0.82
Relative weight: Output λ_X		0.048
Relative weight: Interest rate λ_R		0.236

Note: All parameters are in quarterly frequency.

Table 3: Pseudo-true Values

	Subsample			
	(1) Pre-Crisis	(2) Crisis	(3) Policy-Shift	(4) Post-Crisis
Preference / technology parameters				
Consumption habit h	0.75 (0.00)	0.74 (0.00)	0.90 (0.01)	0.77 (0.00)
Inverse Frisch elasticity ψ	3.79 (0.00)	3.79 (0.17)	3.80 (0.20)	3.79 (0.09)
Elast. of capital utilization cost χ	5.30 (0.00)	5.30 (0.33)	5.30 (0.34)	5.30 (0.00)
Investment adjustment cost S''	2.85 (0.00)	2.85 (0.00)	2.30 (0.07)	2.85 (0.00)
Calvo prices ξ_p	0.84 (0.00)	0.84 (0.00)	0.86 (0.00)	0.84 (0.00)
Price indexation ι_p	0.24 (0.00)	0.24 (0.02)	0.28 (0.02)	0.24 (0.00)
Calvo wages ξ_w	0.71 (0.00)	0.70 (0.01)	0.79 (0.01)	0.71 (0.00)
Wage indexation ι_w	0.11 (0.01)	0.11 (0.02)	0.19 (0.02)	0.11 (0.00)
Shock-related parameters				
Persistence: mon. pol. shock ρ_{mp}	0.14 (0.01)	0.14 (0.01)	0.13 (0.01)	0.14 (0.01)
Persistence: tech. shock ρ_A	0.99 (0.00)	0.99 (0.00)	0.98 (0.00)	0.99 (0.00)
Persistence: gov. shock ρ_G	0.99 (0.00)	0.99 (0.00)	0.99 (0.00)	0.99 (0.00)
Persistence: MEI shock ρ_μ	0.80 (0.00)	0.92 (0.00)	0.91 (0.00)	0.72 (0.00)
Persistence: Price markup shock ρ_p	0.93 (0.00)	0.94 (0.01)	0.95 (0.00)	0.94 (0.00)
Persistence: Wage markup shock ρ_w	0.99 (0.00)	0.97 (0.00)	0.97 (0.00)	0.99 (0.00)
Persistence: Preference shock ρ_b	0.67 (0.00)	0.59 (0.00)	0.68 (0.01)	0.67 (0.00)
Persistence: Risk premium shock ρ_{rp}	0.56 (0.00)	0.61 (0.00)	0.74 (0.00)	0.53 (0.00)
MA parameter: Price markup shock θ_p	0.77 (0.00)	0.77 (0.01)	0.84 (0.01)	0.77 (0.00)
MA parameter: Wage markup shock θ_w	0.90 (0.00)	0.90 (0.00)	0.92 (0.00)	0.90 (0.00)

Table 3: Pseudo-true Values (continued)

	Subsample			
	(1) Pre-Crisis	(2) Crisis	(3) Policy-Shift	(4) Post-Crisis
Shock-related parameters (continued)				
Size: Monetary policy shock σ_m	0.22 (0.00)	0.22 (0.00)	0.22 (0.00)	0.22 (0.00)
Size: Technology shock σ_A	0.88 (0.01)	0.88 (0.01)	0.91 (0.01)	0.88 (0.01)
Size: Government spending shock σ_G	0.35 (0.00)	0.35 (0.00)	0.35 (0.00)	0.35 (0.00)
Size: MEI shock σ_μ	6.01 (0.03)	6.05 (0.00)	7.53 (0.05)	6.03 (0.03)
Size: Price markup shock σ_{p*}	0.14 (0.00)	0.14 (0.00)	0.14 (0.00)	0.14 (0.00)
Size: Wage markup shock σ_{w*}	0.20 (0.00)	0.21 (0.00)	0.19 (0.00)	0.20 (0.00)
Size: Preference shock σ_{b*}	0.04 (0.00)	0.06 (0.00)	0.03 (0.00)	0.04 (0.00)
Size: Risk premium shock σ_{rp}	0.29 (0.00)	1.07 (0.00)	1.14 (0.02)	0.25 (0.00)

Table 4: Welfare Loss Across Periods

	Subsample			
	(1) Pre-Crisis	(2) Crisis	(3) Policy-Shift	(4) Post-Crisis
Taylor rule: Inflation ϕ_π	4.06	4.06	5.36	5.36
Taylor rule: Output ϕ_X	-0.52	-0.52	-0.79	-0.79
Taylor rule: Output growth $\phi_{\Delta X}$	10.45	10.45	10.03	10.03
Inflation σ_π	0.73	0.76	0.75	0.72
Output σ_X	3.29	3.42	3.57	3.44
Interest rate σ_R	1.12	1.25	1.24	1.11
Welfare loss L_0	1.3486	1.5099	1.5335	1.3744
(relative to previous period)	(n.a.)	(+12.0%)	(+1.6%)	(-10.4%)

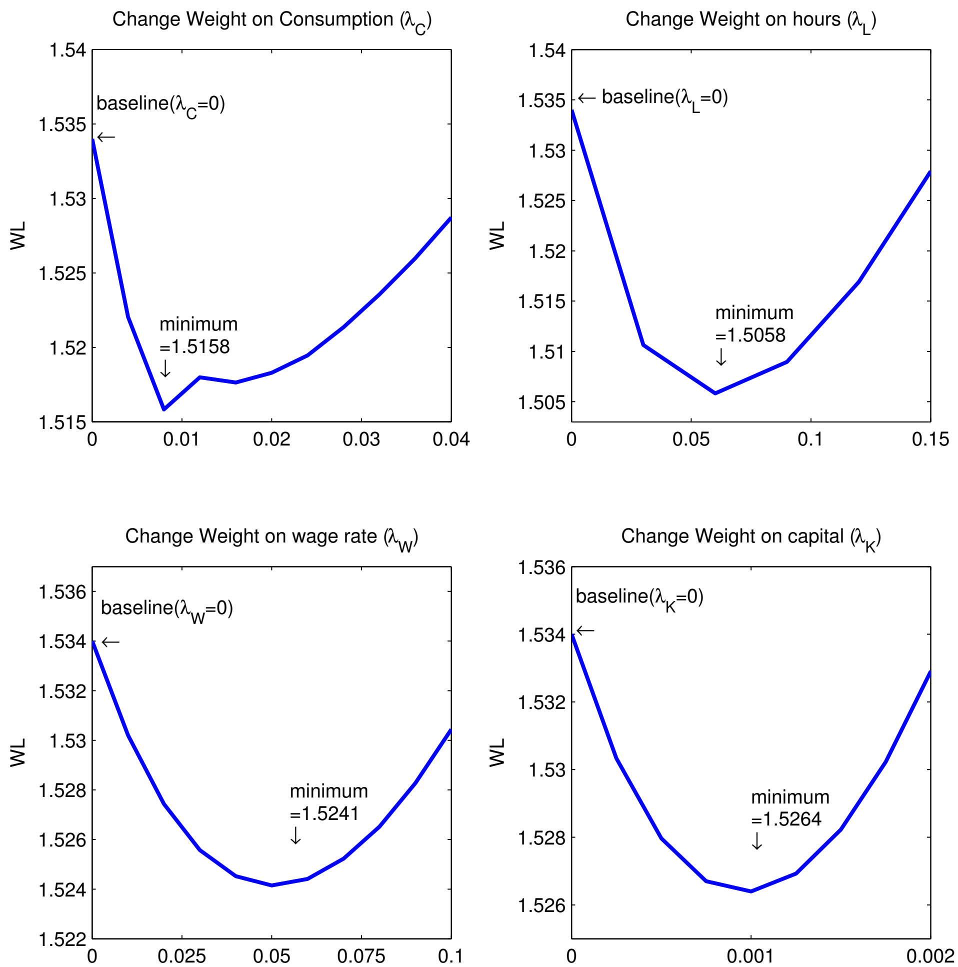
Table 5: Optimal Policy Comparison: GK/BGG

	(1) GK-opt, baseline	(2) GK-opt, $\nu_g = 0$	(3) BGG-opt. baseline
Taylor rule: Inflation ϕ_π	6.57	4.66	5.36
Taylor rule: Output ϕ_X	-0.93	-0.58	-0.79
Taylor rule: Output growth $\phi_{\Delta X}$	17.10	11.28	10.03
Public financial intermediation ν_g	-3.08	n.a.	n.a.
Welfare loss L_0, policy shift period	1.3799	1.5053	1.5335
(relative to BGG-optimal)	(-10.0%)	(-1.8%)	(0.0%)
Welfare loss L_0, post-crisis period	1.3817	1.3486	1.3744
(relative to BGG-optimal)	(+0.5%)	(-1.9%)	(0.0%)

Table 6: Expanded Taylor Rule

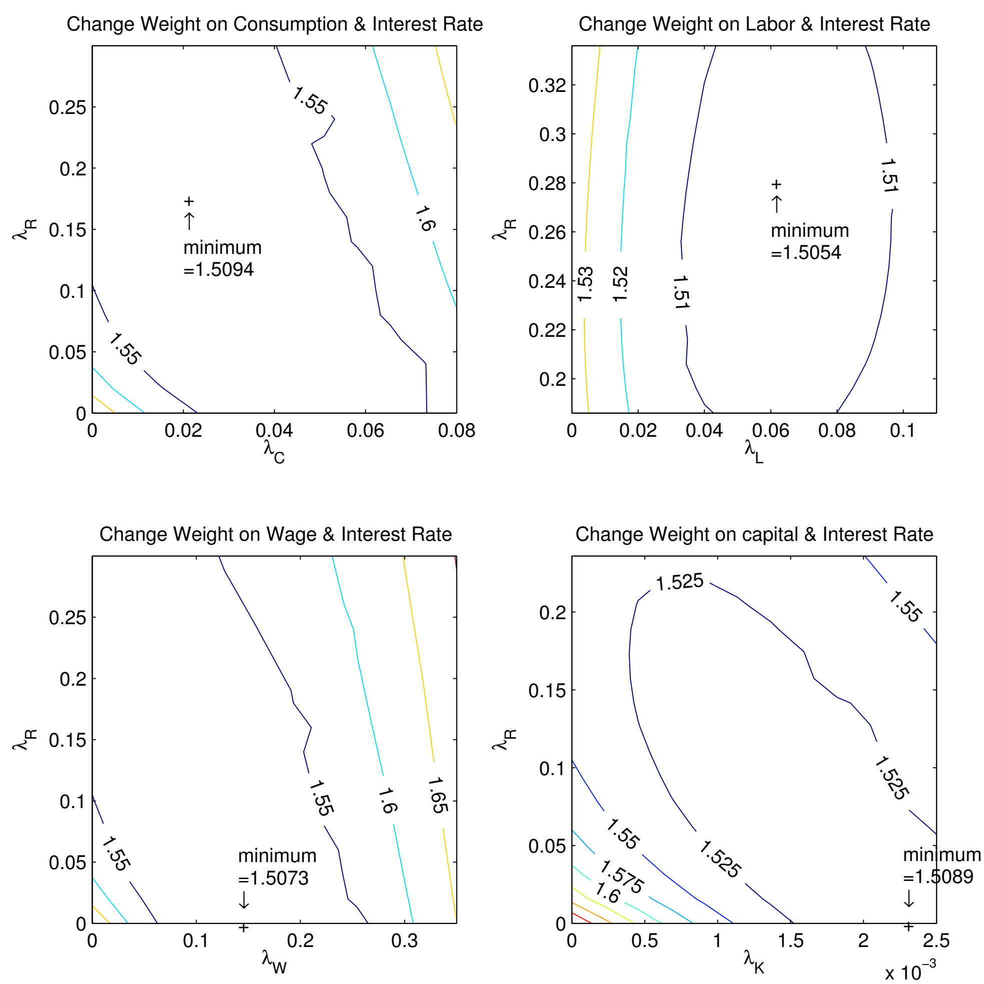
	(1) Add leverage ($CC = \phi$)	(2) Add spread ($CC = spr$)
Taylor rule: ν_{CC}, contemp. rule	0.552	0.010
Taylor rule: ν_{CC}, backward rule	0.532	0.011
Taylor rule: ν_{CC}, forward rule	0.562	0.010
Welfare loss L_0, contemp. rule	1.5117	1.4947
(rel. to baseline BGG-optimal)	(-1.5%)	(-2.6%)
Welfare loss L_0, backward rule	1.5089	1.4878
(rel. to baseline BGG-optimal)	(-1.6%)	(-3.0%)
Welfare loss L_0, forward rule	1.5130	1.5024
(rel. to baseline BGG-optimal)	(-1.4%)	(-2.1%)

Figure 1: Welfare Loss when a Single Weight is Changed



Note: The horizontal axis in each panel represents the weights applied for the additional target variable incorporated in the expanded quadratic loss function, which was set to zero in the baseline.

Figure 2: Welfare Loss when Two Weights are Simultaneously Changed



Note: The horizontal axis in each panel represents the weights applied for the additional target variable incorporated in the expanded quadratic loss function, which was set to zero in the baseline. The vertical axis represents the weight applied for the interest rate smoothing objective which was set to 0.236 in the baseline.