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Output Gap in Presence of Financial Frictions and Monetary Policy Trade-offs

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Abstract

The recent global financial crisis illustrates that financial frictions are a significant source of volatility in the economy. This paper investigates monetary policy stabilization in an environment where financial frictions are a relevant source of macroeconomic fluctuation. We derive a measure of output gap that accounts for frictions in financial market. Furthermore we illustrate that, in the presence of financial frictions, a benevolent central bank faces a substantial trade-off between nominal and real stabilization; optimal monetary policy significantly reduces fluctuations in price and wage inflations but fails to alleviate the output gap volatility. This suggests a role for macroprudential policies.

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I. Introduction

Potential output and the output gap are not observable economic variables. Yet they are crucial variables for policy makers in helping them gauge the stance of policy, be it in setting interest rates or obtaining fiscal balance. Yet, the recent financial crisis has been a sobering experience for economic analysts and policy makers, as it has put in serious doubt previous estimates of potential output and the output gap. Crucially, most estimates of potential output simply focus on the role of labor, capital, technology, and sometimes trade variables, ignoring the role of financial variables. A key motivation behind this study is to introduce the missing link of financial variables to models used to analyze the implications for optimal policy making.[1]

In the Federal Reserve Act the statutory objectives for monetary policy are maximum employment, stable prices, and moderate long-term interest rates. A central bank achieves this by setting the interest rate to counteract deviation of inflation from its desired outcome and minimize fluctuations in the output gap. Within this framework, sustainability is a defining feature of the economy's efficient frontier. However, considering potential output as a non-inflationary component of output is too simplistic; the recent financial crisis illustrates that financial imbalances can build up in a relatively stable inflation environment and ultimately lead to disruptions in the real economy. What are the sources of inefficiencies in the economy? How do financial frictions affect stabilization policies? These are the questions that we aim to answer here.

In this paper, we build on the recent generation of estimated models with financial frictions and financial shocks. We make two contributions to the literature. First, we derive a measure of the output gap that accounts for financial frictions in the data. We further quantify the degree of inefficiency in an economy that is perturbed by inefficient financial shocks in addition to the standard inefficiency shocks to price and wage mark-ups that have so far been considered in the New Keynesian literature (see, Rotemberg and Woodford (1998a) and Galí, Gertler, and López-Salido (2007)). Second, we compute the trade-offs between nominal and real stabilization

[1]There is a growing literature on output gap uncertainty. For the monetary and fiscal policy implications of output gap estimates in times of crisis, see Bouis, Cournéde, and Christensen (2012).

that emerge when the monetary policy authority behaves optimally. The presence of financial frictions implies that the central bank faces an additional source of inefficiency, besides the presence of monopolistic competition and nominal rigidities in goods and labor markets as in the standard New Keynesian model.

We conduct our analysis in the context of an estimated New Keynesian model that is extended to include a financial accelerator mechanism along the lines of Bernanke, Gertler, and Gilchrist (1999) (hereafter BGG (1999)). The New Keynesian core of the model is taken from Justiniano, Primiceri, and Tambalotti (2013) (hereafter JPT (2013)) that uses mark-up as the state of the art reference on monetary policy trade-offs in New Keynesian models without financial frictions. As in Christiano, Motto, and Rostagno (2014) (hereafter CMR (2014)) financial frictions modify the propagation of standard disturbances by amplifying demand shocks and attenuating supply shocks. Moreover, financial frictions are also a source of shocks. We include two inefficient financial shocks as in Gilchrist, Ortiz, and Zakrasjek (2009): a shock to the net worth of firm, that directly affects the availability of credit for the production sector and a shock to the external finance premium that reflects possible tensions in the financial markets.

We define the output gap as the difference between actual output and potential output. Potential output in our economy is unobserved; it is the counterfactual level of output that emerges if prices and wages have been flexible and there are no financial shocks, but firms maintain constant monopoly power in the goods and labor markets. Therefore, the mark-ups are constant at their steady state level. Moreover, the financial wedge is in place and absent financial shocks, it depends on the leverage ratio in equilibrium. In our economy inefficiencies stem from several sources, namely price and wage rigidities, habit persistence, capital accumulation, financial frictions and cost push shocks. Financial frictions, act through two channels in affecting output: the accelerator and financial shocks. Financial shocks are inefficient shocks and explain 21.56% of the volatilities in output in our model. The presence of the accelerator implies a wedge between the expected return on capital and the risk-free rate distorting households' intertemporal decision making behavior. The financial wedge depends on the aggregate financial conditions in the economy.

The evidence presented in this paper underlines the role of financial frictions as the fundamental in the models used for monetary policy formulation; the presence of financial frictions helps to explain the path of historical output gap by enriching the estimated potential output. Using our estimated model, we find that the output gap has been positive during the Great Moderation, up to the onset of the financial crisis. We also construct a time varying measure of financial frictions and further show that this measure is countercyclical and highly correlated with the default risk spread and proxies of financial condition. The monetary policy authority, who wishes to stabilize all its intermediate targets at the same time, faces substantial trade-offs due to financial frictions, together with nominal and real rigidities. We find that under optimal monetary policy, the central bank can stabilize price inflation considerably and (especially) wage inflation at the cost, however, of non-negligible fluctuations in the output gap. To put it differently, the optimal policy prioritizes nominal objectives (price and wage inflation), even if it involves undermining output gap stabilization. Finally, turning to the financial stabilization, we show that the paths of financial variables under the optimal and historical rule track somewhat with each other. However, spread and asset price inflation have been slightly more stationary under the historical interest rate rule.

This work belongs to two strands of the literature. The first relates to the behavior of the output gap in DSGE models. Earlier contributions include Levin, Onatski, Williams, and Williams (2005), Andres, López-Salido, and Nelson (2005) and Edge, Kiley, and Laforte (2008). Sala, Söderström, and Trigari (2008) were the first to obtain a cyclical output gap in an estimated DSGE model with unemployment; their model-based output gap exhibits cyclical properties that resembles measures of the output gap obtained using statistical methods. JPT (2013) and Galí, Smets, and Wouters (2011) relate the model-implied output gap to the stochastic processes driving labor supply shocks and wage mark-up shocks. To the best of our knowledge, our paper is the first that derives the output gap from a model with financial frictions. A relevant empirical work is Borio, Disyatat, and Juselius (2013), which emphasizes the relevance of financial factors for output gap dynamics. They use a statistical estimation approach to draw attention to the effects of the financial cycle on potential output and hence the output gap.

We also build our work based on the literature investigating monetary policy trade-offs using structural models. Most central banks perceive a trade-off between stabilizing inflation and stabilizing the gap between output and potential. However, Blanchard and Galí (2007) show that within small size NK models, there is no trade-off between output gap stabilization and inflation stabilization. This is called "Divine Coincidence". In this world, only cost-push shocks in the New Keynesian Phillips curve, price and wage mark-up shocks can generate trade-offs. As discussed in Galí, Gertler, and López-Salido (2007) and Blanchard and Galí (2007), however, the divine coincidence holds only under strong assumptions: no capital accumulation and no real rigidities in the form of habit persistence or real wage rigidities. Therefore, in medium-scale DSGE models, like Smets and Wouters (2007) where real rigidities and capital accumulation play an important role, the divine coincidence does not hold anymore and all shocks have cost-push effects and generate trade-offs. JPT (2013) provides a quantitative setup to estimate the magnitude of policy trade-offs in a medium-size DSGE model; they find that the policy trade-offs are negligible;[2] that is to say, policymakers are able to almost completely stabilize price inflation, wage inflation, and the output gap, as long as wage mark-up shocks are small. Another related work is Carlstrom, Fuerst, and Paustian (2010) where they compute the optimal monetary policy within a calibrated NK model with agency cost.

In our model, financial frictions act as a new source of inefficiencies affecting the frontier of the economy. We compute the counterfactual level of output under the Ramsey optimal monetary policy, in the spirit of JPT (2013). We are not the first to look at the optimal mone-

[2]This is called *"Trinity"* in their terminology.

tary policy in a model with financial frictions. Fendoglu (2011) computes the Ramsey monetary policy in a calibrated financial accelerator model, driven by three disturbances, namely, productivity, government spending, and risk. Other papers that look at the optimal monetary policy in models with financial frictions are Curdia and Woodford (2009), and Moessner (2006). In a similar setup, Faia and Monacelli (2007) look at the optimal monetary policy rules in a financial accelerator model driven by technology and government spending shocks. We contribute to this literature by conducting our analysis in an estimated (rather than a calibrated model) model driven by eleven exogenous disturbances, including two financial shocks, which differentiate our paper from JPT (2013).[3]

The rest of the paper is organized as follows. Section 3 provides the details of the theoretical model, and Section 4 describes the empirical evaluation of the model and variance decomposition analysis. Section 5 discusses the impact of financial frictions on potential output and the output gap. Optimal monetary policy is described in Section 6. Section 7 concludes.

II. Model

This section describes our model of the US business cycle. This is a quantitative DSGE model, which contains many frictions that affect nominal, real, and financial decisions of households, entrepreneurs, and firms. The model nests the standard New Keynesian model of JPT (2013). The baseline NK model is essentially Christiano, Eichenbaum, and Evans (2005), and Smets and Wouters (2007), which we augment by financial accelerator block of BGG (1999). The economy consists of seven classes of agents: households, entrepreneurs, intermediate goods producer firms, final goods producer firms, the employment agency, central banks and the government. In what follows, we explain the underlying function of each sector in the economy.

A. Final Goods Producers

Perfectly competitive final goods producers combine a continuum of intermediate goods $Y_t(i)$, indexed with $i \in [0,1]$, according to a Dixit-Stiglitz technology to produce the homogenous good Y_t:

$$Y_t = \left[\int_0^1 Y_t(i)^{\frac{1}{1+\Lambda_{p,t}}} \, di \right]^{1+\Lambda_{p,t}}. \tag{1}$$

[3]The presence of financial shocks is particularly important because these shocks are inefficient. It has been well known since JPT (2010) and CMR (2014) that financial shocks absorb a large part of the explanatory power of shocks to the marginal efficiency of investment once financial variables are used in the estimation.

$\Lambda_{p,t}$ is the curvature of the aggregator. It is related to the degree of substitutability across different intermediate goods in the production of the final good. $\Lambda_{p,t}$ varies exogenously over time in response to price mark-up shocks ($\varepsilon_{p,t}$). The stochastic process of this shock is as follows, where ρ_p is the mark-up of the process:

$$log(1+\Lambda_{p,t}) \equiv \lambda_{p,t} = (1-\rho_p)\lambda_{p,t} + \rho_p\lambda_{p,t-1} + \varepsilon_{p,t}, \tag{2}$$

where $\varepsilon_{p,t} \sim i.i.d.N(0,\sigma_p^2)$. With the monopolistic competition, price is a mark-up over marginal cost. The natural level of output, which prevails in the steady state, is the level of output when the mark-up is at its constant steady state value. Natural output would be a function of productivity and, as we will see later, because of the price indexation scheme that we adopt, there is no price dispersion in steady state. Hence the steady state level of inflation does not affect welfare. Inflation, on the other hand, would be a function of expected inflation, the output gap, and the mark-up shock. The variation in the mark-up affects the competitiveness in the intermediate goods market; hence, the central bank faces a tradeoff between inflation stabilization and output stabilization at its natural level, which does not change in response to the mark-up.

The price of the final good (P_t) is obtained from profit maximization and the zero profit condition of the final goods producer firm. It is an aggregate of the prices of intermediate goods $P_t\,(i)$:

$$P_t = \left[\int_0^1 P_t\,(i)^{-\frac{1}{\Lambda_{p,t}}}\,di\right]^{-\Lambda_{p,t}}. \tag{3}$$

The demand function for each intermediate good i is given by:

$$Y_t\,(i) = \left(\frac{P_t\,(i)}{P_t}\right)^{-\frac{1+\Lambda_{p,t}}{\Lambda_{p,t}}} Y_t. \tag{4}$$

B. Intermediate Good Producers

The intermediate goods are produced by monopolists using the following production function:

$$Y_t\,(i) = A_t^{1-\alpha} K_t\,(i)^{\alpha}\,L_t\,(i)^{1-\alpha} - A_t F, \tag{5}$$

where $K_t(i)$ and $L_t(i)$ represent the quantity of capital and labor used by firm i in the production sector. F is a fixed cost of production, indexed to technology, so that profits are zero in the steady state. A_t is the Solow residual of the production function. Its growth rate z_t ($z_t \equiv \Delta \log A_t$) is stationary and varies exogenously over time in response to technology shocks ($\varepsilon_{z,t}$). The dynamic of the technology shock follows an AR(1) process with $\varepsilon_{z,t} \sim i.i.d.N(0, \sigma_z^2)$:

$$z_t = (1 - \rho_z)\gamma + \rho_z z_{t-1} + \varepsilon_{z,t}. \tag{6}$$

Each monopolist chooses its price subject to a Calvo (1983) mechanism. Every period a fraction ξ_p do not choose prices optimally but simply index their current price according to the rule:

$$P_t(i) = P_{t-1}(i)\, \pi_{t-1}^{\iota_p} \pi^{1-\iota_p} \tag{7}$$

$$\pi_t \equiv \frac{P_t}{P_{t-1}}, \tag{8}$$

where ι_p is the degree of price indexation. π_t is the gross inflation rate and π represents its steady state value. Note that this steady state value does not depend on the i, therefore there is no price dispersion in steady state. As explained in JPT (2013), this indexation scheme has the desirable property that the level of steady state inflation does not affect welfare and the level of output in steady state. Remaining firms set their price $\widetilde{P}_t(i)$ by maximizing profits intertemporally:

$$E_t \sum_{s=0}^{\infty} \xi_p^s \frac{\beta^s \Lambda_{t+s}}{\Lambda_t} \left\{ \left[\widetilde{P}_t(i) \left(\prod_{j=0}^{s} \pi_{t-1+j}^{\iota_p} \pi^{1-\iota_p} \right) \right] Y_{t+s}(i) - \left[W_t L_t(i) + r_t^k K_t(i) \right] \right\}, \tag{9}$$

where $\frac{\beta^s \Lambda_{t+s}}{\Lambda_t}$ represents the discount factor of the household that owns the firm, being Λ_t the marginal utility of consumption, whereas W_t and r_t^k indicate the nominal wage and nominal rental rate of capital, respectively.

C. Employment Agencies

Perfectly competitive employment agencies, or labor packers, combine differentiated labor services, indexed with $j \in [0, 1]$, into homogeneous labor using the following technology:

$$
\begin{aligned}
L_t &= \left[\int_0^1 L_t\left(j\right)^{\frac{1}{1+\Lambda_{w,t}}} dj \right]^{1+\Lambda_{w,t}} \\
\lambda_{w,t} &\equiv \log(\Lambda_{w,t}+1),
\end{aligned} \tag{10}
$$

where $\Lambda_{w,t}$ is the elasticity of substitution across different labor varieties. The real wage can be obtain by multiplying the mark-up $(\Lambda_{w,t}+1)$ by the ratio of the marginal utility of leisure over the marginal utility of consumption. $\lambda_{w,t}$ is an $i.i.d.N\left(0,\sigma_w^2\right)$ wage mark-up shock. Employment agencies maximize profits in a perfectly competitive environment. The demand function for labor of type j is given by:

$$
L_t\left(j\right) = \left(\frac{W_t\left(j\right)}{W_t}\right)^{-\frac{1+\Lambda_{w,t}}{\Lambda_{w,t}}} L_t. \tag{11}
$$

Profit maximization combined with the zero profit condition would lead to the optimal wage paid by intermediate good producer firms. This aggregate wage is as follows:

$$
W_t = \left[\int_0^1 W_t\left(j\right)^{-\frac{1}{\Lambda_{w,t}}} dj \right]^{-\Lambda_{w,t}}. \tag{12}
$$

For each labor type, we assume the existence of a union, which represents all workers of that type. Wages are set subject to Calvo lotteries. In parallel with the goods market, every period a fraction ξ_w of unions index the wage according to the rule:

$$
W_t\left(j\right) = W_{t-1}\left(j\right)\left(\pi_{t-1}e^{z_{t-1}}\right)^{\iota_w}\left(\pi e^{\gamma}\right)^{1-\iota_w}, \tag{13}
$$

where γ represents the growth rate of the economy along a balanced growth path. This indexation scheme implies that output is independent of the steady state value of wage inflation. The remaining unions choose the wage optimally by maximizing the utility of their members, subject to labor demand.

D. Households

The household sector is composed of a large number of identical households, each composed by a continuum of family members indexed by j. All labor types are represented in each household, and family members pool wage income and share the same amount of consumption as in Merz

(1995). Capital is produced within the household by combining investment goods (I_t) and undepreciated capital $\left(\overline{K_t}\right)$, according to the following technology:

$$\overline{K_{t+1}} = (1-\delta)\,\overline{K_t} + \mu_t \left(1 - S\left(\frac{I_t}{I_{t-1}}\right)\right) I_t, \tag{14}$$

where δ is the depreciation rate and the function $S\left(\frac{I_t}{I_{t-1}}\right) = \frac{\zeta}{2}\left(\frac{I_t}{I_{t-1}} - e^{\gamma}\right)^2$ captures investment adjustment costs, as in Christiano, Eichenbaum, and Evans (2005). In steady state $S(1) = S^{'}(1) = 0$ and $S^{''}(1) = \zeta$. μ_t varies exogenously over time in response to shocks to the marginal efficiency of investment ($\varepsilon_{\mu,t}$), following Greenwod, Hercowitz, and Hufmann (1988) and Justiniano, Primiceri, and Tambalotti (2011):

$$\log \mu_t = \rho_\mu \log \mu_{t-1} + \varepsilon_{\mu,t} \qquad \varepsilon_{\mu,t} \sim i.i.d.N(0, \sigma_\mu^2). \tag{15}$$

The representative household takes the price of capital (Q_t) and the price of investment goods (P_t), as well as labor income, as given and maximizes the utility function:

$$E_t \left\{ \sum_{s=0}^{\infty} \beta^s b_{t+s} \left[\log\left(C_{t+s} - hC_{t+s-1}\right) - \varphi_t \int_0^1 \frac{L_{t+s}\left(j\right)^{1+\nu}}{1+\nu} dj \right] \right\}. \tag{16}$$

Log utility ensures the existence of a balanced growth path, as the technological progress is non-stationary. C_t stands for consumption, h for the degree of habit formation, and ν for the inverse of the labor supply elasticity. b_t varies exogenously over time in response to intertemporal preference shocks $\varepsilon_{b,t}$ as does φ_t in response to intertemporal labor supply shock $\varepsilon_{\varphi,t}$.

$$\log b_t = \rho_b \log b_{t-1} + \varepsilon_{b,t}, \qquad \varepsilon_{b,t} \sim i.i.d.N(0, \sigma_b^2) \tag{17}$$

$$\log \varphi_t = (1-\rho_\varphi)\varphi + \rho_\varphi \log \varphi_{t-1} + \varepsilon_{\varphi,t}, \qquad \varepsilon_{\varphi,t} \sim i.i.d.N(0, \sigma_\varphi^2). \tag{18}$$

Households maximize utility subject to the budget constraint

$$P_t C_t + P_t I_t + T_t + B_{t+1} + Q_t\left(1-\delta\right)\overline{K_t} = \int_0^1 W_t\left(j\right) L_t\left(j\right) dj + R_t B_t + Q_t \overline{K_{t+1}} + O_t. \tag{19}$$

Households use funds to buy consumption and investment goods, to pay lump sum taxes, and to save in a one-period-bond (B_{t+1}) that pays a gross nominal return R_t in each state of nature. This bond is the source of external funds for entrepreneurs and plays a crucial role in the financial accelerator mechanism. Expenses are financed with labor income, revenues from previous period savings, revenues from selling capital to entrepreneurs, and profits from ownership of firms in the intermediate goods sectors (O_t).

E. Entrepreneurs

Entrepreneurs, indexed by l, are essential for the transformation of raw physical capital, produced by the household, into capital suitable for intermediate goods production that can be rented to firms. At the end of period t, entrepreneurs use their net worth, N_{t+1}, to buy raw capital, $\overline{K_{t+1}}$, at price Q_t. They further convert it to productive capital for production at time t + 1, (K_{t+1}). In order to purchase the capital, the entrepreneur borrows $Q_t\overline{K_{t+1}} - N_{t+1}$ from a mutual fund or a financial intermediary. The financial intermediary transfer funds from households to entrepreneurs. In the BGG (1999) framework, households are risk averse and entrepreneurs are risk neutral; hence, the entrepreneur is the only party that bares all the risk in the loan contract. After purchasing the capital, entrepreneurs experience an idiosyncratic shock, i.i.d. ω_t, which determine the efficiency of their project. Therefore, their efficient capital is $\omega_t\overline{K_{t+1}}$ and they choose the capital utilization rate (u_t) and transform installed capital into effective capital according to

$$K_{t+1}(l) = \omega_t(l)\, u_t(l)\, \overline{K_{t+1}}(l). \tag{20}$$

$\omega_t(l)$ is independently drawn across time and across entrepreneurs. It is log-normally distributed with unit mean and variance σ^2.[4] Effective capital is then rented to firms at the competitive nominal rental rate r_t^k. Therefore the return on the capital received by the entrepreneurs is $r_{t+1}^k\omega_t u_t\overline{K_{t+1}}$. As in Levin, Onatski, Williams, and Williams (2005), the cost of capital utilization has the form $a(u_t) = \rho\frac{u_t^{1+\chi}-1}{1+\chi}$, such that in steady state $u = 1$, $a(1) = 0$, and $\chi \equiv \frac{a''(1)}{a'(1)}$.

Finally, at the end of period $t+1$ each entrepreneur is left with $(1-\delta)\omega_t(l)\overline{K_{t+1}}(l)$ used and depreciated capital. This capital is sold to households in competitive markets at the price Q_{t+1}. The aggregate depreciated capital bought by household is $(1-\delta)\overline{K_{t+1}}(l)$ and they further use their technology given by Equation 14 to build $\overline{K_{t+2}}$. Given the assumptions of the model, the

[4]The time variation of parameters in the model has not been considered, in this chapter, to keep the model tractable. There is a debate in the literature casting doubts on how structural are the structural parameters (Fernandez-Villaverde and Rubio-Ramirez (2007)) and the issue of Lucas critiques. Financial frictions are likely to change over time, for example, due to the financial liberalization process, as shown by Fuentes Albero (2012). Another interesting extension of this work would be an inclusion of time varying financial friction mechanisism into the model.

optimal level of utilization is common across entrepreneurs and the nominal rate of return on capital is given by $R^k_{t+1}(l) = \omega_t(l)\, R^k_{t+1}$, where

$$R^k_{t+1} = \frac{[r^k_{t+1}u_{t+1} - a(u_{t+1})]P_{t+1} + (1-\delta)\,Q_{t+1}}{Q_t}, \tag{21}$$

As explained above, at the end of period t each entrepreneur uses its own net worth $N_{t+1}(l)$ and borrows $B_{t+1}(l)$ from households to purchase capital at price Q_t

$$B_{t+1}(l) = Q_t\overline{K_{t+1}}(l) - N_{t+1}(l)\,. \tag{22}$$

Following BGG (1999), the financial intermediary that intermediates funds between households and entrepreneurs cannot observe the idiosyncratic shock $\omega_t(l)$ unless it pays a monitoring cost. At the end of period t, the lender and the borrower agree on a gross nominal interest rate $Z_{t+1}(l)$. Let $\overline{\omega_t}$ be the cut-off value of ω_t that divides entrepreneurs who cannot repay the loan from those who can. Then,

$$\overline{\omega_t}Q_t\overline{K_{t+1}}(l)\,R^k_{t+1} = B_{t+1}(l)\,Z_{t+1}(l)\,. \tag{23}$$

Entrepreneurs whose $\omega_t(l)$ is lower than $\overline{\omega_t}$ declare bankruptcy and the intermediary must pay a monitoring cost (μ) proportional to the realized gross payoff to recover the remaining assets. The presence of asymmetric information and monitoring costs implies that external finance is costly such that there is a premium $\left(S_t = \frac{R^k_{t+1}}{R_t}\right)$ over the risk-less rate that depends inversely on the borrower's net worth:

$$\frac{R^k_{t+1}}{R_{t+1}} = \left(1 - \frac{N_{t+1}}{Q_{t+1}\overline{\overline{K_{t+1}}}}\right)\left[(1-\mu)\int_0^{\bar{\omega}} \omega dG(\omega) + (1-G(\bar{\omega}))\bar{\omega}\right]^{-1}. \tag{24}$$

In equilibrium, the optimal leverage of entrepreneurs depends on their expected return on capital $E_tR^k_{t+1}$ linear rule:[5]

$$\begin{aligned} \frac{E_tR^k_{t+1}}{R_t} &= \psi_t\tilde{S}\left(\frac{N_{t+1}}{Q_t\overline{\overline{K_{t+1}}}}\right) \\ \log\psi_t &= \rho_\psi\log\psi_{t-1} + \varepsilon_{\psi,t}, \qquad \varepsilon_{\psi,t}\sim i.i.d.N(0,\sigma^2_\psi), \end{aligned} \tag{25}$$

[5] In a log-linearized solution, the remaining moments are insignificant.

where ψ_t varies exogenously over time in response to shocks to the external finance premium ($\varepsilon_{\psi,t}$), following Gilchrist, Ortiz, and Zakrajsek (2009). A possible micro-foundation for this shock is studied in CMR (2014). Entrepreneurs are risk-neutral and have a finite horizon. The survival probability ϑ_t varies exogenously over time in response to net worth shocks ($\varepsilon_{\vartheta,t}$), as in Gilchrist and Leahy (2002). This assumption ensures that entrepreneurs will always need external finance to fund investments. Every period a fraction $1-\vartheta_t$ of entrepreneurs exit and consume the residual assets, while ϑ_t new entrepreneurs enter the market with an endowment W_t^e.[6] The law of motion for net worth is given by

$$\begin{aligned} N_{t+1} &= \vartheta_t \left[R_t^k Q_{t-1}\overline{K_t} - R_{t-1}B_t\right] + W_t^e \\ \log\vartheta_t &= \rho_\vartheta \log\vartheta_{t-1} + \varepsilon_{\vartheta,t}, \qquad \varepsilon_{\vartheta,t} \sim i.i.d.N(0,\sigma_\vartheta^2). \end{aligned} \tag{26}$$

F. Central Bank

The monetary policy authority sets the interest rate following a feedback rule

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_R} \left[\left(\frac{\left(\prod_{s=0}^{3}\pi_{t-s}\right)^{\frac{1}{4}}}{\pi_t^*}\right)^{\phi_\pi} \left(\frac{(X_t/X_{t-4})^{1/4}}{e^\gamma}\right)^{\phi_X}\right]^{1-\rho_R} e^{\varepsilon_{R,t}}, \tag{27}$$

Where R is steady state gross nominal interest rate and ρ_R is the degree of interest rate smoothing. ϕ_π is the control parameter which measures the response of interest rate to the deviation of inflation from its target, π_t^*. Likewise ϕ_X measures the reaction to the annual GDP growth, $\frac{X_t}{X_{t-4}}$, from its steady state level, e^γ. $\varepsilon_{R,t}$ is an $i.i.d.N\left(0,\sigma_R^2\right)$ monetary policy shock. The inflation target, π_t^*, varies exogenously over time in response to inflation targeting shocks ($\varepsilon_{\pi,t}$), as in Ireland (2007), to account for the low frequency behavior of inflation:

$$\begin{aligned} \log\pi_t^* &= (1-\rho_\pi)\pi + \rho_\pi \log\pi_{t-1}^* + \varepsilon_{\pi,t}, \\ \varepsilon_{\pi,t} &\sim i.i.d.N(0,\sigma_\pi^2) \end{aligned} \tag{28}$$

When we compute the optimal output, we ignore this monetary policy rule and we assume that the central bank maximizes the utility of the representative agent.

[6] The endowment is of a negligible size, so in the estimation we do not consider it.

G. Government

Government finances its expenditure G_t by collecting the lump sum tax T_t, which appears in the households' budget constraint. Public spending is subject to a spending shock and is a time varying fraction of output:

$$
\begin{aligned}
G_t &= (1 - 1/g_t)Y_t & (29)\\
\log g_t &= (1-\rho_g)\log g + \rho_g \log g_{t-1} + \varepsilon_{g,t} & (30)\\
\varepsilon_{g,t} &\sim \; i.i.d.N(0, \sigma_g^2),
\end{aligned}
$$

where g is the steady state value of government spending. Finally, output is divided between consumption, investment, adjustment cost of investment and government consumption G_t; hence the aggregate resource constraint is given by:

$$
Y_t = C_t + I_t + S(\frac{I_t}{I_{t-1}})I_t + G_t. \tag{31}
$$

Equations (1) to (30) determine endogenous variables. The stochastic behavior of the system of linear rational expectations equations is driven by exogenous disturbances: price mark-up shock ($\lambda_{p,t}$), total factor productivity (z_t), wage mark-up shock ($\lambda_{w,t}$), labor supply shock (ϕ_t), intertemporal preference shifter (b_t), marginal efficiency of investment (μ_t), spread shock (ψ_t), net worth shock (ϑ_t), government spending (g_t), and monetary policy (ε_R) shocks.[7] In the next section we will explain the empirical evaluations of the model.

III. Empirical Evaluation

This section describes our empirical analysis. We first estimate the model presented in the previous section using a Bayesian technique. We then investigate the parameters' posterior estimation and variance decompositions of the shocks.

[7]The stochastic singularity problem is addressed as the number of shocks equal the number of endogenous series employed in the estimation, as suggested by Smets and Wouters (2007). The shocks are identified because of estimation approach: first, because of the assumption on orthogonality of these exogenous processes, and second, one to one mapping of observable variables used to estimate the model with the shocks providing sufficient information content to specify them. Finally, as highlighted by Kocherlakota (2007), shocks need a structural interpretation.

A. Bayesian Estimation

The model is estimated using the Bayesian approach with ten observables. The data are quarterly from 1964Q2 to 2009Q4. We use eight key US macroeconomic time series, similar to JPT (2013). In addition, we use two financial series, namely the credit spread and the net worth, to account for the main financial variables in the model. Our observables are as follows: log difference of GDP, log difference of consumption, log difference of investment, inflation, log difference of two measures of nominal hourly wage, nominal interest rate, log difference of hours worked, log difference of net worth, and the credit spread. The model is expressed in log deviation from steady state for simulation purposes. The data are obtained from Federal Reserve Economic Data - FRED - St. Louis Fed, Bureau of Labor Statistics and NIPA. The data feeds the models in annualized per capita log-difference, except those variables which are defined in terms of annualized rates, such as interest rates and the credit spreads, which are used in levels.

Real per-capita GDP is nominal GDP divided by the civilian non-institutional population (16 years and older) and the GDP deflator. The civilian population series contains several breaks, due to census-based population adjustments. We smooth the series by uniformly splicing over a 10-year window.[8] The real per-capita consumption is the sum of non-durables and services, divided by the civilian non-institutional population and the GDP deflator. Real per-capita investment is the sum of the nominal consumer durables and total nominal private investment, divided by the civilian non-institutional population and the GDP deflator. The inflation rate is the log difference of the GDP deflator. We use the effective Federal Funds Rate for the nominal interest rate. Per-capita hours is the number of hours worked in the total economy, divided by the civilian non-institutional population. The choice of series for hours is driven by Francis and Ramey (2009); they show that low-frequency movements in the standard measure of hour are sectoral shifts in hours and the changing age composition of the working-age population. Therefore, we use the hours worked in the total economy as opposed to nonfarm business sector because it accounts for the sectoral shifts and, hence, does not have a pronounced low frequency behavior. Turning to financial observables, real per-capita net worth growth is the log difference of total net worth, divided by the civilian non-institutional population and the GDP deflator. Total net worth series is obtained from the balance sheet of nonfarm noncorporate businesses. This series is highly correlated with Dow Jones Wilshire 5000, which is used in CMR (2014). Finally, we measure the credit spread by the difference between the BAA-rated corporate bond yield and the Federal Funds Rate (FFR). BAA yield can account for the lending rate and FFR for the risk free rate, which is set by central bank, within the context of the model. This essentially motivate our choice of spread series. [9]

[8]Splicing corrects for structural breaks in the time series by using the data points for 10 years around the structural break point to connect the series in a smooth way that allows for econometrics analysis.

[9]BGG (1999) proxies the credit spread by the spread between the prime lending rate (PLR) and the 6-month Treasury bill rate. PLR series contain a structural break and, since late 1990, follows the FFR; this make it an unattractive choice. Gilchrist, Yankov, and Zakrajsek (2009) construct a corporate credit spread index, which mainly capture the long run default risk. Gilchrist, Ortiz, and Zakrajsek (2009) uses this measure to estimate the spread; this could potentially be a good choice for our estimation but, since this index is only available from the 1973Q1 to 2008Q4, we can not use it. Two recent works by CMR (2014), and Fuentes-Albero (2013)

Wage Inflation and Trade-offs. We estimate wage inflation using two series, compensations and earnings, in order to absorb high frequency variations in the measurement errors. Boivin and Giannoni (2006a) was the first to propose an estimation of wage inflation using two series. Recently this methodology is used by JPT (2013) and Gali, Smets, and Wouters (2011).[10] JPT (2013) provides a comprehensive discussion about the relationship between the importance of wage mark-up shocks in explaining business cycle fluctuation and the choice of wage observables. In our model, the presence of financial frictions significantly reduces the importance of wage mark-up shocks in explaining the macroeconomic volatilities. But, since we are building our analysis based on JPT (2013), we have to control for all their implementation details, in order to make sure that our results are purely driven by the presence of financial frictions. Hence, we use a similar estimation approach to the one described in JPT (2013). This approach is essentially what drives their main result, the so-called "Trinity trade-offs". In a New Keynesian model without financial frictions, the monetary policy trade-offs are small when two wage series are used to estimate the model; while trade-offs are non-negligible and significant when the model is estimated using only one wage series. We estimate the model using one and two wage series but we only discuss the trade-offs in two-wage series case.

To match the wage inflation variable in the model, $\Delta \log W_t$, with two data series, we use a simple i.i.d. observation error, using the following measurement equations:

$$\begin{bmatrix} \Delta log(NHC_t) \\ \Delta log(HE_t) \end{bmatrix} = \begin{bmatrix} 1 \\ \Gamma \end{bmatrix} \Delta \log W_t + \begin{bmatrix} e_{1,t} \\ e_{2,t} \end{bmatrix} \tag{32}$$

$$e_{i,t} \sim i.i.d.N(0, \sigma^2_{e_{i,t}}) \quad i = 1, 2, \tag{33}$$

where $\Delta log(NHC_t)$ represents the growth rate of nominal compensation per hour in the total economy; $\Delta log(HE_t)$ represents the growth rate of average hourly earnings of production and nonsupervisory employees. Γ is a loading coefficient of the second wage series and the first wage series' loading coefficient is normalized to one. $e_{1,t}$ and $e_{2,t}$ are observation errors which are independently and identically distributed.

The estimated variances of wage mark-up shocks are summarized in table 1. As it is seen

use the spread between the BAA-rated corporate bond and the 10-year US Treasury bill rate. This choice is an attempt to account for the maturity mismatch. Taheri Sanjani (2013) shows that the maturity mismatch problem does still exist in the BAA-TB10 spread, it further provides a thorough discussion on defualt and liquidity components of the spread.

[10] JPT (2013)'s underlying assumption is that both measures of wage series imperfectly match the notion of the wage variable in the model and, therefore, one can capture this mismatch by using the measurement error.

Table 1: Posterior Modes - Variance of Wage Mark-up Shock

	2 wage series	Compensations	Earnings
$100\sigma_w$	0.058	0.283	0.105

from the table, in two wage series case, the variance is very small, while when only one wage series is used the variance is almost five times larger.[11] In what follows we discuss the prior distribution and Bayesian estimation steps.

Prior distribution of the parameters. In what follows, we describe the prior distributions and posterior estimations of the parameters in the model. Starting from the priors, for the parameters that are similar to the JPT (2013) model, we follow their distributional assumptions. We borrow the prior assumptions of the parameters that are related to the financial frictions block from CMR (2014) and BGG (1999). Four parameters are fixed in the estimation procedure. First, the steady state of the depreciation rate of capital is fixed at 0.02. Second, the steady state ratio of government spending to GDP is set at 0.2. Third, we set the steady state net wage mark-up to 25 percent, as we cannot identify it. Fourth, the persistence of the inflation target shock is set to 0.995.[12]

The standard errors for the innovations are assumed to follow an Inverse-Gamma distribution with a mean changing from 0.10 to 1.00 and a standard deviation of 1.00, except for the inflation target equation which is set to 0.03, corresponding to a rather loose prior. The covariance matrix for the innovations is diagonal. The persistence of the AR (1) processes is Beta-distributed with a mean of 0.60, except the autoregressive parameter of the growth rate of TFP process, z(t), which is set to 0.40.[13] The mean of the steady state probability of default, $F(\bar{\omega})$, is set to 0.007. The value of the mean in BGG (1999) is 0.75 percent and in Fisher

[11] It is shown in JPT (2013) that when the wage inflation is estimated using only one wage series, the variance of the wage mark-up shocks is almost six times larger than in their baseline case where they use two wage series as observables. Therefore, when one wage series is used, the wage mark-up shock is implausibly large. In such case, policy makers who care about macroeconomic stabilization face a trade-off; central bank has to de-stabilize aggregate real activity (output gap), in order to reduce the volatility of price and, especially, wage inflation; and hence, the trinity doesn't hold any more.

[12] Following to JPT (2013), there is a common view that: "the exogenous movements of the inflation target explain very low frequency behavior of inflation."

[13] In the model, the TFP process, A(t), has a unit root, i.e. some technology shocks have a permanent effect. The growth rate of the TFP process, z(t), is stationary. Having a stochastic trend in technology is standard in the literature (see JPT(2013), SW(2007), Fuentes-Albero (2012)). In setting the prior for the parameters of the New Keynesian block, we follow JPT(2013), which is standard in the DSGE literature.

(1999) is 0.974. The prior mean of the monitoring cost is 0.27, which is within the empirically plausible range of 0.2-0.36 proposed by Carlstrom and Fuerst (1997). The steady state value of the spread shock is set at 0.26, following CMR (2014). The priors on the structural parameters are fairly diffuse and are set following the standard measures in the literature, see SW (2007), and Del Negro, Schorfheide, Smets, and Wouters (2007). Table 2 summarizes the distributional assumptions of the priors and the posterior estimates of the model.

Bayesian Estimation. We estimate the posterior modes by maximizing the log posterior function, which combines the prior information on the parameters with the likelihood of the data. In the next step, the Metropolis-Hastings algorithm is used to get a complete picture of the posterior distribution and to evaluate the marginal likelihood of the model. We simulate the model for 20,000 Metropolis Hastings iterations. The model is estimated over the full sample period. Conditional on the sample information, the Kalman smoother can also be used to estimate the historical path of the model's endogenous variables, which include potential and optimal output. Figure 13, in the Appendix, shows the multivariate Brooks and Gelman's convergence statistic of MCMC simulation. As is seen in the figure, convergence occurs after 13,000 draws.

Posterior estimates of the parameters. A number of observations are worth making regarding the estimated processes for the exogenous shock variables. Overall, the estimation results seem to be consistent with JPT (2013) for non-financial parameters and with CMR (2014) for the financial parameters. The data appear to be very informative for the stochastic processes of the exogenous disturbances. In our model, the presence of financial frictions decreases the importance of the investment shock, labor supply shock, and monetary policy reaction to the output growth and inflation, compared to the economy of JPT (2013) without financial frictions. By comparing the posterior means across two models we can observe that the variance of the marginal efficiency of investment shock drops to 4.89, compared to 7.56 in JPT (2013). Further, the mean of autocorrelation parameters of this shock drops to 0.2, compared to 0.69 in JPT. The variance of labor supply shock drops to 2.76 from 4.73 in JPT. The price stickiness is also estimated to be smaller (0.67 comparing to 0.84 in JPT). Investment adjustment cost is lower (2.43 compared to 3.93 in JPT). Control parameters of monetary policy feedback rule also drop from 2.32 and 0.85 in JPT to 1.43 and 0.09, for inflation reaction parameter, and output growth reaction parameter respectively. The posterior mode of the steady state probability of default is 0.004 and this value is close to its prior mean. The mode of monitoring cost is 0.43, which is not very close to the prior mean. The distance of the prior mean from the posterior mode indicates informativeness of data about the parameter. It seems that the data are very informative about monitoring cost but not as much about steady state probability of default, $\mathrm{F}(\bar{\omega})$. In the next section we will investigate the variance decompositions of the model.

Table 2: Prior Distributions and Posterior Parameter Estimates in the Model

				Prior		**Posterior**			
	Name	Description	Distribution	Mean	S.DV	Mean	Mode	5%	95%
	$100\sigma_{mp}$	Std MP	Inv. Gamma	0.15	1.00	0.27	0.29	0.25	0.30
	$100\sigma_z$	Std Tech.	Inv. Gamma	1.00	1.00	0.85	0.82	0.77	0.93
	$100\sigma_g$	Std Gov. Spending	Inv. Gamma	0.50	1.00	0.37	0.36	0.34	0.40
	$100\sigma_\mu$	Std Investment	Inv. Gamma	0.50	1.00	4.89	6.31	3.22	6.63
	$100\sigma_p$	Std Price Mark-up	Inv. Gamma	0.15	1.00	0.13	0.17	0.10	0.16
	$100\sigma_\psi$	Std Labor Supply	Inv. Gamma	1.00	1.00	2.72	1.93	1.81	3.65
	$100\sigma_b$	Std Preference	Inv. Gamma	0.10	1.00	0.04	0.03	0.03	0.06
	$100\sigma_w$	Std Wage Mark-up	Inv. Gamma	0.15	1.00	0.08	0.06	0.04	0.11
	$100\sigma_{\pi^*}$	Std Inflation Target	Inv. Gamma	0.05	1.00	0.06	0.04	0.03	0.08
	$100\sigma_{e_1}$	Std Measurement Error 1	Inv. Gamma	0.15	1.00	0.51	0.49	0.46	0.57
5***Stochastic**	$100\sigma_{e_2}$	Std Measurement Error 2	Inv. Gamma	0.15	1.00	0.24	0.31	0.21	0.27
	$100\sigma_S$	Std Spread	Inv. Gamma	0.15	1.00	0.18	0.18	0.17	0.20
	$100\sigma_{nw}$	Std Net worth	Inv. Gamma	0.15	1.00	0.98	0.87	0.81	1.18
	ρ_R	Auto. MP	Beta	0.60	0.20	0.74	0.71	0.70	0.78
	ρ_z	Auto. Tech	Beta	0.40	0.20	0.03	0.03	0.00	0.07
	ρ_g	Auto. Gov. Spending	Beta	0.60	0.20	0.99	1.00	0.99	1.00
	ρ_μ	Auto. Investment	Beta	0.60	0.20	0.35	0.20	0.14	0.51
	ρ_p	Auto. Price Mark-up	Beta	0.60	0.20	0.97	0.21	0.96	1.00
	ρ_ψ	Auto. Labor Supply	Beta	0.60	0.20	0.99	0.98	0.98	1.00
	ρ_b	Auto. Preference	Beta	0.60	0.20	0.54	0.65	0.43	0.65
	ρ_S	Auto. Spread	Beta	0.60	0.20	0.89	0.90	0.86	0.91
	ρ_{nw}	Auto. Net worth	Beta	0.60	0.20	0.82	0.89	0.72	0.91
	α	Capital Share	Normal	0.30	0.05	0.18	0.17	0.16	0.20
	ι_p	Price Indexation	Beta	0.50	0.15	0.07	0.13	0.02	0.11
	ι_w	Wage Indexation	Beta	0.50	0.15	0.04	0.04	0.01	0.07
	100γ	SS Tech. Growth	Normal	0.50	0.03	0.47	0.47	0.43	0.51
	h	Habit Formation	Beta	0.60	0.10	0.84	0.86	0.80	0.88
	λ_p	SS Price Mark-up	Normal	0.15	0.05	0.21	0.16	0.14	0.27
	$\log(L_{ss})$	SS log Hours	Normal	0.00	0.50	0.003	0.004	-0.81	0.84
	$100 * \pi$	SS Inflation	Normal	0.63	0.10	0.29	0.27	0.18	0.39
4***Structural**	$100(\beta^{-1} - 1)$	Discount Factor	Gamma	0.25	0.10	0.18	0.15	0.09	0.27
	ν	Inverse Frisch	Gamma	2.00	0.75	2.33	1.60	1.41	3.22
	ξ_p	Price Stickiness	Beta	0.66	0.10	0.67	0.80	0.64	0.71
	ξ_w	Wage Stickiness	Beta	0.66	0.10	0.73	0.83	0.67	0.79
	χ	Elasticity Util. Cost	Gamma	5.00	1.00	5.51	4.94	3.57	7.12
	S''	Investment Adjusted Costs	Gamma	4.00	1.00	2.43	3.24	1.74	3.06
	ϕ_π	Reaction inflation	Normal	1.70	0.30	1.48	1.45	1.22	1.79
	ϕ_Y	Reaction GDP growth	Normal	0.40	0.30	0.09	-0.16	-0.08	0.28
	Γ	Loading Coefficient	Normal	1.00	0.50	0.62	0.64	0.56	0.67
	σ	Std log-normal distribution	Gamma	0.26	0.10	1.14	1.12	0.93	1.34
	$F(\bar{\omega})$	SS Probability of Default	Beta	0.01	0.007	0.005	0.004	0.002	0.008
	μ	Monitoring Cost	Beta	0.275	0.15	0.47	0.43	0.26	0.66

B. Variance Decomposition

The variance decompositions (VDC) for variables in the model are computed at business cycle frequency. Table 3 reports the contributions of the 11 most important shocks in the model to the variance of macroeconomic variables. The first result to stress is that with the presence of the financial shock, the marginal efficiency of investment shock is less important than in the model without financial frictions. The explanatory power of the spread shocks for output, investment, hours of work, spread, and the rental rate of capital is very high. The technology shock is the most important shock for most of the macroeconomic variables. Price mark-up shocks are the main drivers of inflation volatility. Most of the variations in consumption are explained by the preference shocks and technology shocks. Finally, the measurement errors seem to have no explanatory power for the variables listed; therefore we don't show them in the table.

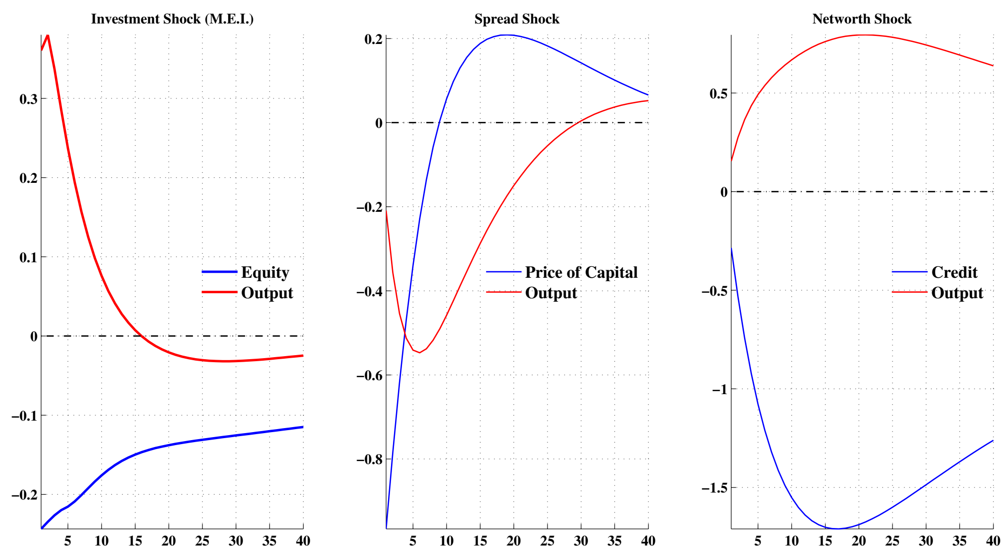

Figure 1: Impulse response functions to the financial shocks

In the New Keynesian DSGE model of JPT (2013), without financial frictions, almost half of output variation is explained by the marginal efficiency of investment shocks, while the TFP shock is the second most significant shock. In an economy with information asymmetry, where the spread between borrowing and lending is non-zero, costly state verification puts in place a mechanism to monitor the risk in entrepreneurship activities. Uncertainty in an entrepreneurial project imposes a risk that affects borrowers' financial position and hence the cost of funding that they face. A rise in the cost of funding, limits the demand for productive capital, and as a result the production and the output of the economy. The spread shock is a demand shock and implies a procyclical price of capital. One the other hand, the marginal efficiency of investment shock is a supply shock and implies that the value of net worth (or the stock market equity) is countercyclical. By including financial observables in our estimation procedure, we can decompose the uncertainty related part of the investment shock. This is the

Table 3: Variance Decompositions at Business Cycle Frequency (%)

	MP	**Tech.**	**Gov. Sp.**	**M.E.I**	**Price MU.**	**Labor Sup.**	**Preference**	**Wage MU**	**Infl. Targ.**	**Spread**	**Net Worth**
Output	10.26	21.58	4.71	8.39	1.48	11.03	15.7	0.46	4.82	14.43	7.13
Consumption	0.93	31.21	1.61	0.24	0.08	7.23	56.09	0.06	0.7	0.22	1.63
Investment	10.85	21.02	0.04	12.71	1.66	4.38	4.56	0.44	4.71	21.67	17.95
Hours	10.69	20.89	4.89	7.94	1.56	11.24	15.02	0.48	4.96	14.97	7.36
Wage	0.14	85.14	0.06	0.38	10.5	0.63	0.42	1.65	0.1	0.43	0.55
Inflation	0.62	17.28	0.24	0.28	42.36	0.09	2.75	0.42	25.04	1.51	9.39
Interest Rate	72.17	10.97	0.13	0.19	4.79	0.23	1.19	0.21	6.2	0.25	3.68
Spread	0.05	0.72	0	0.09	0.01	0.02	0.04	0	0.02	94.12	4.92
Net worth	2.96	18.32	0.82	0.41	0.57	1.62	0.51	0.01	0.84	6.71	67.24
Real Rate	60.25	9.94	0.25	0.03	7.22	0.08	2.12	0.2	14.65	0.72	4.56
Rental Rate	16.8	19.82	3.41	1.46	1.94	5.79	2.78	0.03	3.55	27.98	16.45
Capital	3.38	59.07	0.25	9.52	0.65	2.63	4.21	0.23	1.57	9.03	9.46

main reason that in the presence of the financial accelerator block, the data favors the spread shock over the investment shock. Net worth shock is also a demand shock, but since they produce countercyclical movements in borrowings (or credit), our VDC analysis doesn't give much importance to this shock in explaining the business cycle. Impulse response functions (IRF) presented in figure 1 make the above discussion clear. Finally, we note that, our IRF and VDC results are largely consistent with CMR (2014).

IV. Frictions and Output Gap

In this section we study the impact of financial frictions on the efficient JPT (2013) frontier of the economy and the output gap. Financial frictions act through two channels in affecting output: the accelerator and financial shocks. Exogenous disturbances to the external finance premium and equity would lead output to depart from its efficient frontier. These financial shocks are inefficient shocks and explain 21.56% of the volatilities in output (VDC table). The presence of the BGG accelerator implies a wedge between the expected return on capital and the risk-free rate; this wedge further distorts the households' intertemporal decision-making behavior and hence the economy on aggregate. Moreover, the financial accelerator is a function of the aggregate financial conditions in the economy; the health of the credit market and the banking sector determine the ease in borrowing-lending activities and the availability of finance for investment projects. This ultimately determines the level of economic activity that can be sustained and the efficient frontier of the overall economy. We contribute to the literature by disentangling the impact of these two channels, using a quantitative model-base framework. The evidence presented here highlights the importance of the financial accelerator mechanism in understanding the historical path of output. In what follows, we discuss the path of potential output, output, and the output gap of the economy.

A. Potential Output and Output

Potential output in our economy is unobserved and it is the counterfactual level of output that emerges if prices and wages have been flexible and there are no financial shocks, though firms maintain constant monopoly power in the goods and labor markets. Therefore, the mark-ups are constant at their steady state level. Moreover, the financial wedge is in place and absent financial shocks, it depends on the leverage ratio. Such notion of the potential output is what we call the third-best equilibrium.

The first-best equilibrium, or efficient allocation, is the equilibrium prevailing under perfect competition in goods and labor markets, with no nominal rigidities and no financial frictions, an absence of financial wedge and financial shocks. The second best equilibrium is when we relax the condition on mark-ups and assume they are constant but non-zero. Thus it is the allocation under perfect financial markets (no financial frictions), with no nominal rigidities, but where firms maintain constant monopoly power in the goods and labor markets, implying the mark-ups are constant at their steady state level. While first- and second-best outputs vary over time, the gap between these two remains constant. However, the gap between first- and third-best equilibria depends on the time-varying leverage ratio. Comparing the potential outputs across the models with and without frictions, helps in understanding the accelerator channel, while comparing the associated outputs highlights the joint impact of financial shocks and the accelerator.

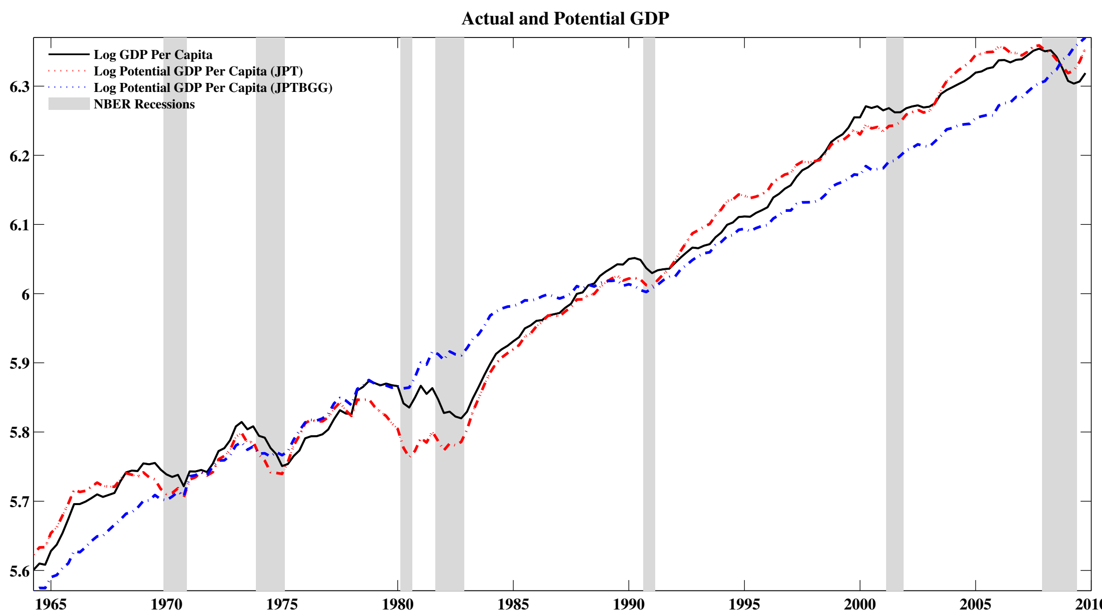

Figure 2: US GDP and potential outputs implied by the estimated models with and without financial frictions

Figure 2 plots the logarithm of US GDP and the posterior median of potential outputs inferred from the model with and without financial frictions (JPTBGG and JPT respectively). The shaded area corresponds to the National Bureau of Economic Research (NBER) recessions. As is clear from the graph, all three outputs fluctuate around almost the same balanced growth path. With the accelerator mechanism explicitly embedded in the model, potential output is higher than the counterpart in the economy without financial frictions, during the 80s. More importantly, it falls below the potential output implied by the model without financial frictions over last 20 years. The other interesting observation is that the output gap is positive and had been increasing since the start of the Clinton administration in 1993 up to the onset of the recent mortgage crisis. This could be due to easy and loose financial conditions and availability of credit in the market during this period. Easy money helped boosting the economy and, as a result, the realized output exceeded its potential. The output gap seems to have experienced a free-fall to a negative value by the start of the financial turmoil. This drop in the output gap is related to the increase in the cost of funding due to the financial distress. This evidence underlines the important role of financial frictions in improving the ability of the model to track fine historical events.

In the JPT economy without financial friction, the Euler equation implies the rental rate of capital to be equal to the risk-free interest rate:

$$\frac{\partial U(t)}{\partial C(t)} = \beta E_t R^k_{t+1}[\frac{\partial U(t+1)}{\partial C(t+1)}].$$

Presence of financial frictions imposes a new inefficient wedge, the so-called the 'financial wedge'. The financial wedge between the expected return to capital and the risk-free rate distorts households' intertemporal decision-making. This wedge depends on the leverage ratio and the contractual share of returns going to the lender. In the equilibrium, absent financial shocks, the contractual share of returns going to lenders is 1, so the financial wedge depends solely on the leverage ratio:

$$\frac{R^k_{t+1}}{R_{t+1}} = 1 - \underbrace{\frac{N_{t+1}}{Q_t K_{t+1}}}_{wedge}.$$

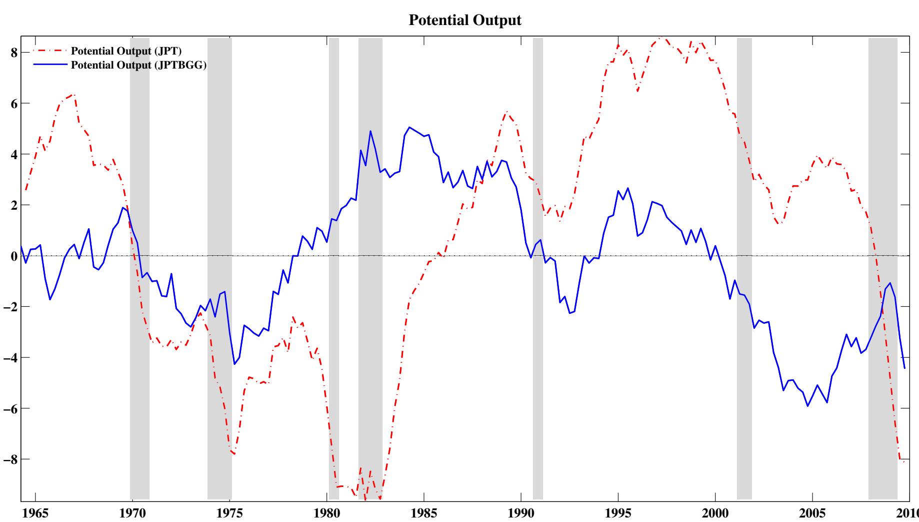

Figure 3: Potential output implied by the estimated models with and without financial frictions

From the above discussion we conclude that fluctuation in the potential output is driven by two sources: (1) the steady state of wage and price mark-ups and (2) the time-varying leverage ratio. Next, we focus more closely on cyclical behavior of the economy. Figure 3 depicts the potential outputs inferred from the JPT model (second-best allocation) in red dotted line and the JPTBGG model (third-best allocation) in solid blue line. Model implied potential output is more volatile than HP filter-potential output. HP filter is a moving average therefore, it is a slow-moving process. In the DSGE model potential output moves with TFP and demand shocks, these can be very volatile and white noise-like because of the nature of quarterly growth series. Several observations are worth making. First, the third-best allocation (JPTBGG potential) is less volatile than the second-best allocation (JPT potential). Second, during the great moderation, the JPTBGG potential output is lower than the JPT potential.[14] This would imply a higher leverage ratio, availability of easy credit, and enhanced financial conditions during this period.

To better understand the dynamic interaction of financial frictions with the frontier of the economy, we start with underpinning some of the properties of the financial wedge. We construct a time-varying measure of financial frictions in the US post-war data. This measure is based on our structural model. At any point in time, this measure is the difference between the output gaps across the two economies, JPT and JPTBGG. Figure 4 illustrates our measure of the financial wedge. Both channels of financial frictions-shocks and the accelerator-are present in this measure. The blue line is our normalized, time-varying BGG measure. The grey bars are the NBER recession lines. The red dashed line is the normalized, default risk spread, constructed as the distance between BAA and AAA corporate bond yields. The measure of financial frictions is highly correlated with the default risk; Taheri Sanjani (2013) provides a comprehensive discussion of default risk spread and its relationship to financial frictions. The shaded areas correspond to the NBER recessions. They highlight the pronounced countercyclical behavior of the DSGE-based financial frictions, which peak during the recessions. The highest peak occurred during the early 80s recession. The peak of this recession was in the last quarter of 1982, when the US nationwide unemployment rate reached 10.8%, the highest since the Great Depression. Another interesting observation is that both default risk spread and frictions in the financial market have been very high during the early-80s crisis; while, in the recent crisis, financial frictions didn't increased as much as the default risk spread. Starting from the onset of the recent financial turmoil in 2007Q4, the default risk spread increase by more than four fold by 2008Q4. During this period, BGG frictions increased 1.5 times. [15]

Figure 12 in the Appendix plots time-varying financial frictions with 2 measures of financial condition: (1) the Chicago Fed National Financial Conditions Credit Subindex (NFCICREDIT) in solid black and (2) the Chicago Fed National Financial Conditions Risk Subindex (NFCIRISK) in dashed red. One can observe that financial condition indices are highly correlated with the BGG frictions. The correlation with the credit subindex is 0.62 and with the risk subindex is 0.53, for the period between 1973Q1 till 2009Q4. We provide more information about these two series in the Appendix.

[14]Potential output could become negative if the labor income or capital input decline sharply. This could happen if, for example, unemployment goes up and labor force participation declines sharply or if firms faced with large capacity overhang scrap existing capital.

[15]The start of quantitative easing 1 (QE1) and the forward guidance in Nov 2008 seems to be coincide with a substantial decline in the default risk spread and a moderate drop in the index of financial frictions.

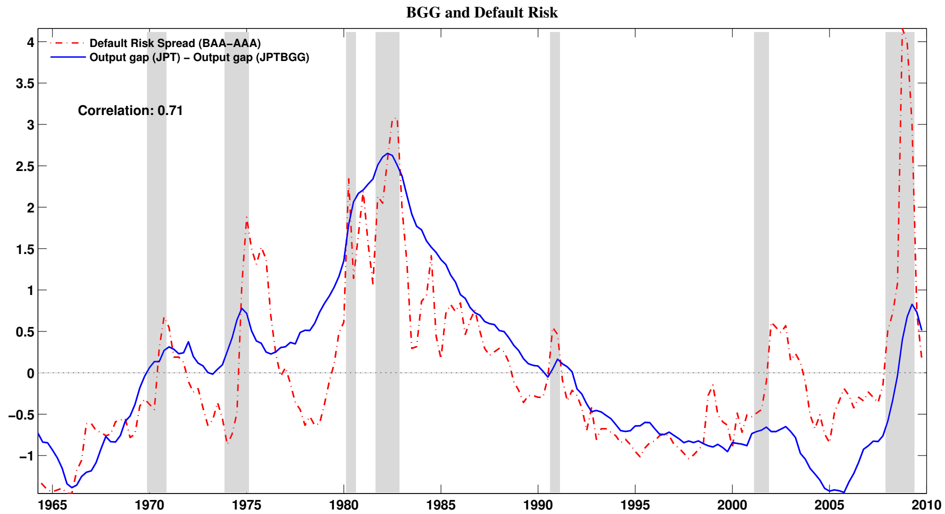

Figure 4: Time-varying financial frictions and default risk spread (Normalized series)

B. Output Gap

Computing output gap accurately is crucial in setting the stance of monetary and fiscal policies. Yet, in the wake of the recent financial crisis most traditional measures of output gap have fallen short in accounting for imbalances that are broader than inflationary ones, such as financial imbalances and housing market imbalances. Most estimates of potential output simply focus on the role of labor, capital, technology, and sometimes trade variables, and ignore the role of financial variables. This section discusses the role of financial variables in understanding the output gap and optimal monetary policy implications.

Figure 5 presents the DSGE-based output gap inferred from the NK models with and without financial frictions and the unemployment wedge. The top panel demonstrates the output gap constructed from DSGE with financial frictions (JPTBGG) in a solid blue line and the gap from the NK-DSGE model of JPT, without financial frictions, in a dash red line. The presence of financial frictions allowed by our reformulation has a substantial impact on the estimated output gap, which now looks considerably more plausible. It can capture the negative output gap during the early 1980s recessions. Additionally, it plunges during the recessions. The bottom panel is from Gali, Smets and Wouters (2011). It illustrates two versions of the output gap, as implied by the estimated NK-DSGE models with and without unemployment, respectively. The solid line is the output gap drawn from the model with unemployment, and the dashed line is inferred from the model without unemployment. This panel shows that the separate identification of the labor supply exogenous process and addition of the unemployment wedge, in Gali, Smets, and Wouters (2011), has a significant effect on the estimated output gap. By comparing these two panels, we can observe that our JPTBGG version of the output gap has a similar

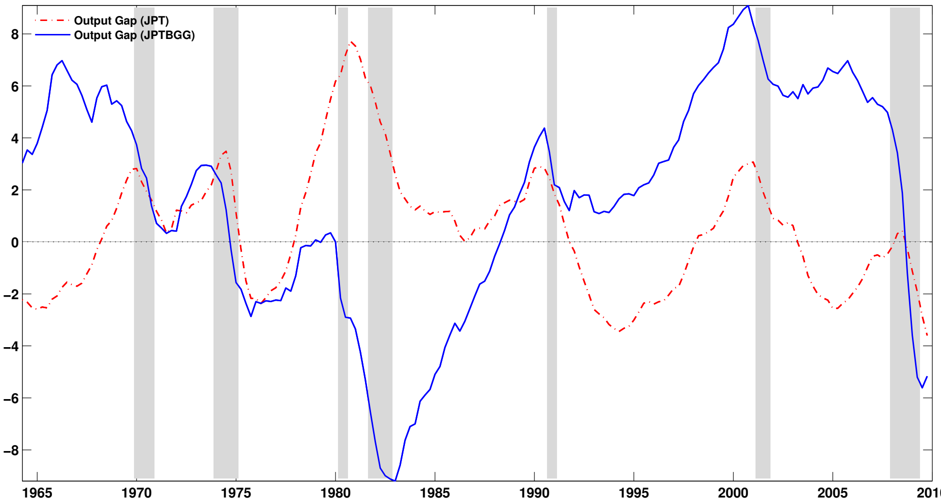

Figure 5: Output gap implied by the estimated models with and without financial frictions

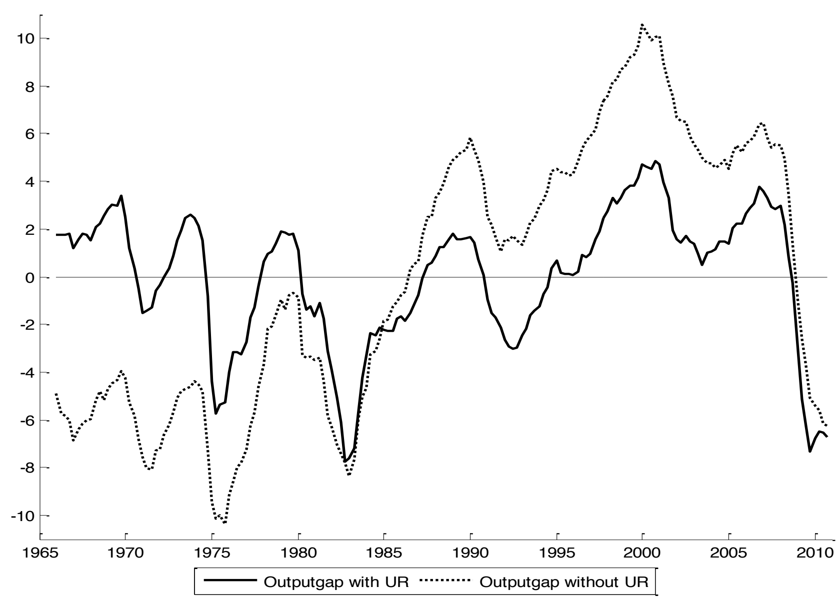

Figure 6: Output gap implied by the estimated models with and without unemployment

pattern to the one from Gali, Smets and Wouters (2011).[16] From the above discussions we can

[16]The similarity between our output gap and the output gap implied by Gali, Smets, and Wouters (2011), further provides a promising avenue for our future research. One can study the output gap inferred from a reformulated JPTBGG model, which is extended by the unemployment theory of Gali (2010). This allows for identifying the financial frictions channel from the unemployment rate channel.

conclude that financial frictions improve the performance of the DSGE models by providing a more realistic picture of the economy. The output gap implied by our model has been positive during the great moderation, up to the onset of the financial crisis. Starting from the onset of the crisis, it sharply declined and reached its lowest level, -5.6, in 2009Q2 and bounced back after that. Next, we try to analyze the differences between the two output gaps by computing the variance decomposition of shocks in the JPT and JPTBGG models.

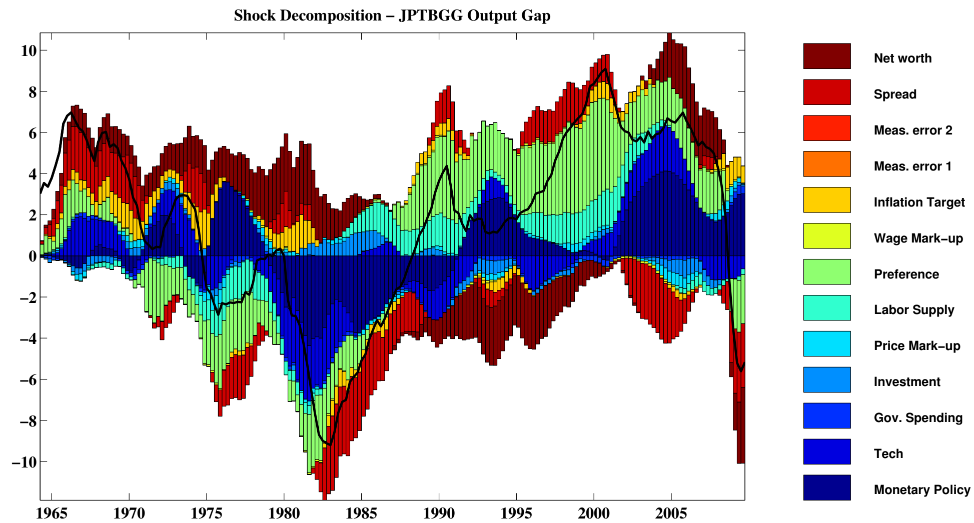

Figure 7: Variance decomposition of the shocks - the JPTBGG model

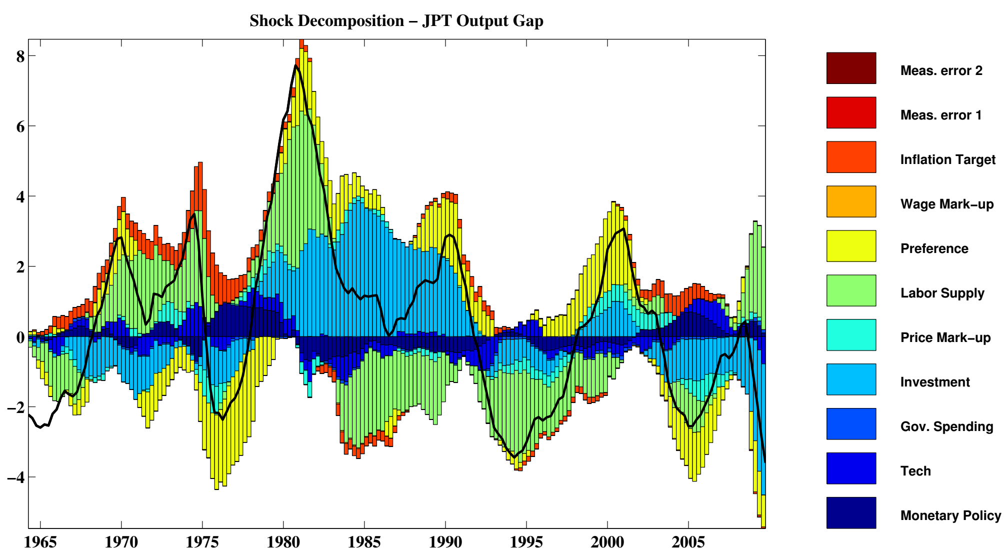

Figure 8: Variance decomposition of the shocks - the JPT model

Variance decomposition shows the decomposition of the effects of shocks upon impact.

Figures 7 and 8 illustrate the variance decompositions of model with and without financial frictions, respectively. The positive output gap of the JPT model during the 1980s crisis can be explained by the positive contribution of investment shock, labor supply shock, and intertemporal preference shock. Figure 8 implies that during the great moderation, the size of investment shocks have been small and often negative and labor supply shocks had a negative aggregate contribution. One the other hand, the negative output gap of JPTBGG during the 1980s crisis can be explained by the negative contributions of spread shock, preference shock, and monetary policy and technology shock. Also as it is observed in Figure 7, the positive output gap during the great moderation can be explained by the positive contribution of intertemporal preference shock, technology shock, monetary policy shock, and labor supply shock. The model with financial frictions can capture the dynamic of monetary policy, agents' intertemporal preference, investment process, and labor supply far better than the model without financial frictions. Inclusion of financial frictions helps to correct for the impact of labor supply shock.

For our final remark, we checked the robustness of our results with respect to the estimation sample size. More specifically, we estimated both JPT and JPTBGG models using a shorter dataset, starting from 1964Q2 up to the recent crisis, 2006Q4. Then we computed the implied output gaps. Figure 14 in the Appendix demonstrates these two output gaps inferred from models with and without financial frictions. One can observe that the output gap implied by our model behaves very robustly; and this suggests that DSGE models with financial frictions could be a good tool to forecast output gap. This provides an interesting avenue for our future research.

B.1. Monetary Policy Trade-offs

How successful has optimal policy been in stabilizing the economy? In an environment where financial frictions are relevant source of inefficiencies, can a stabilization policy counteract the inefficient fluctuations in output and inflation? What would be its impact on financial variables? In what follows, we aim to answer these questions. To do so, we first compute the model's optimal equilibrium path. This is the welfare maximizing equilibrium, chosen by the central planner under commitment, subject to the economy's constraints.[17] We then compute the counterfactual evolution of the economy using the approach proposed by JPT (2013). Specifically, we use the solution of the model under the Ramsey problem to compute the historical path of output and other endogenous variables that would have emerged if policy had always been optimal and the economy had been perturbed by the same series of estimated shocks in the baseline specification in which the Taylor interest rate rule had been in place as the central bank monetary policy instrument.

[17] JPT (2013) uses the linear quadratic approach proposed by Benigno and Woodford (2006) and implemented by Altissimo, Curdia, and Rodriguez-Palenzuela (2005).

$$QLF = W_y(Y_t - Y_t^*)^2 + W_\pi(\pi_t - \pi_t^*)^2$$

We compute the Ramsey policy directly, as we have financial variables in our model; hence the choice of an appropriate Linear Quadratic (LQ) objective function is not immediate.

In our economy, the monetary authority faces a trade-off in stabilizing output around its potential, stabilizing price, and wage inflation. The trade-off stems from different frictions and wedges in our economy: price and wage rigidities, habit persistence, capital accumulations, financial frictions, and cost push shocks. Therefore, at equilibrium the output gap, spread, desired price and wage are not constant. In order to study these trade-offs more comprehensively, we compute the optimal equilibrium path of the model.

C. Optimal Monetary Policy

The solution for the Ramsey optimal monetary policy is a competitive equilibrium such that households maximize utility subject to their budget constraints, firms maximize profits, the government budget constraint holds, and all markets clear, Woodford (2003). We characterize this optimal equilibrium following the Ramsey policy[18] by computing the first order approximation of the policy that maximizes the policymaker's objective function[19] under the constraints provided by the equilibrium path of the economy. Note that the optimal equilibrium is not affected by the inflation target shock, π_t^*, and the monetary policy shock, $\varepsilon_{R,t}$, since we replaced the interest rate by the optimal rule. [20] Next, we compute the counterfactual path of output and of the other endogenous variables that would have been observed if the following would hold: 1) the policy had always been optimal; this would allow us to use transition functions obtained from the equilibrium solution under the Ramsey problem. 2) The endogenous variables start from the same initial points as in the baseline economy. 3) The economy had been disturbed by the same sequence of shocks estimated in the baseline specification under the historical interest rate rule. The state space evolution of the model under the counterfactual equilibrium is as follows:

$$y_t = y_{estim}^{ss} + A_{opt}(y_{t-1} - y_{estim}^{ss}) + B_{opt}u_{estimt}, \tag{34}$$

[18]The experience of the recent crisis shows that inflation targeting might not be sufficient anymore to sustain macroeconomic stability. Maintaining financial stability and price stability jointly requires more than the tool of monetary-policy. As a result, more and more central banks are resorting to macroprudential policies and non-orthodox monetary policy. Given the scope and objective of this chapter, we consider interest rate policy because for most of my sample period the interest rate rule provided a good representation of monetary policy. For the last part of the sample this is not the case because of the non-orthodox policy adopted by the Fed, in light of the zero lower bound (ZLB). We do not model such alternative non-standard policies because the observation sample size is too short for properly identifying such episodes and, secondly, it is not straightforward to model simultaneously all types of non-standard policies. The model uses a short cut to account for any misspecification of the interest rate changes beyond the Taylor rule by using shocks.

[19]In reality, the US congress established the legislative objectives for monetary policy in the Federal Reserve Act; this includes maximum employment, stable prices, and moderate long-term interest rates.

[20]Literature on optimal monetary policy has been fruitful: JPT (2013), Fendoglu (2011), Levin, Onatski, Williams, and Williams (2005), Schmitt-Grohe and Uribe (2007), and Christiano, Ilut, Motto, and Rostagno (2010) compute optimal, or Ramsey, monetary policy in medium-scale DSGE models. Debortoli, Maih, and Nunes (2011) also considers the loose commitment problem where policymaker's degree of commitment is not constant.

where y^{ss}_{estim} is the steady state value of the variables under the estimated model with a Taylor rule policy instrument. $u_{estim}(t)$ is the historical path of shocks under the Taylor rule interest rate policy. A_{opt} and B_{opt} are the transition matrices of the model under the optimal policy solution.

Figures 9 and 10 present the path of actual and optimal macroeconomic variables implied by model with and without financial frictions. We focus on the macro objectives, namely output gap, price inflation and wage inflation. In the top panel we present the variables implied by our model, JPTBGG. In the bottom panel, we present our replication of the JPT (2013) trinity result. The blue lines are the variables under Taylor rule monetary policy, while the red dotted lines are computed under Ramsey optimal monetary policy rule. Optimal and actual outputs are both presented in deviation from potential output inferred from baseline specification. The output gap under optimal policy is significantly more stationary, and the amplitude of the fluctuations is smaller, nonetheless, the optimal output gap is not negligible, unlike the counterpart in model without financial frictions (JPT (2013)). The model without financial frictions implies that an output stabilization policy under optimal rule is successful. But when we take into account the effect of financial frictions, we observe that price and wage inflation are significantly less volatile under the optimal policy, but a stabilization policy fails to counteract the fluctuation in output gap; that is to say, in our economy, output-inflation stabilization trade-off is substantial. Therefore, a policymaker cannot achieve all its stabilization objectives at the same time and it has to prioritize stabilizing price and wage inflation, even if it involves undermining output gap stabilization. This trade-off is mainly due to the presence of financial frictions and nominal rigidities. Interestingly, plot (b) and plot (c), which demonstrate price and wage inflations respectively, are very similar to the ones in JPT (2013). Therefore, we conclude that monetary policy cannot achieve the Pareto-optimal equilibrium that would occur under no financial frictions and flexible wages and prices; that is, the model exhibits a trade-off in stabilizing the output gap, price inflation, and wage inflation, all at the same time.

The discrepancy between the economy's path that prevails under the historical interest rate rule and under the optimal path is striking. This observation is also present in JPT (2013). Some of our conjectures about the reasons behind this discrepancy are: first, it might be because of the underlying differences between the statutory or real objectives of the Fed and those adopted by our model. The monetary policy rule in our model is simplified and is not flexible enough to be fine-tuned or re-adjusted to capture historical events.[21] The other reason can be that policy might have been less effective ex-post than it was thought ex-ante, due to unobserved economic and financial uncertainty. Uncertainty can distort the FOMC's communications with households and businesses. This ultimately results in suboptimal decision-making behavior and non-Pareto optimal equilibrium outcomes. Finally, as is proposed in the literature (Clarida, Gali, and Gertler (2000), Cogley and Sargent (2005), and Primiceri (2006)) policy could have been misguided during some periods.

[21] The Taylor rule is a rule-of-thumb, and its empirical validity owes to its ability to track policy during the time of relatively modest volatility. Therefore, during the periods of crisis when there is sizable economic and financial volatilities, it is bound to be overly naive in tracking the policy.

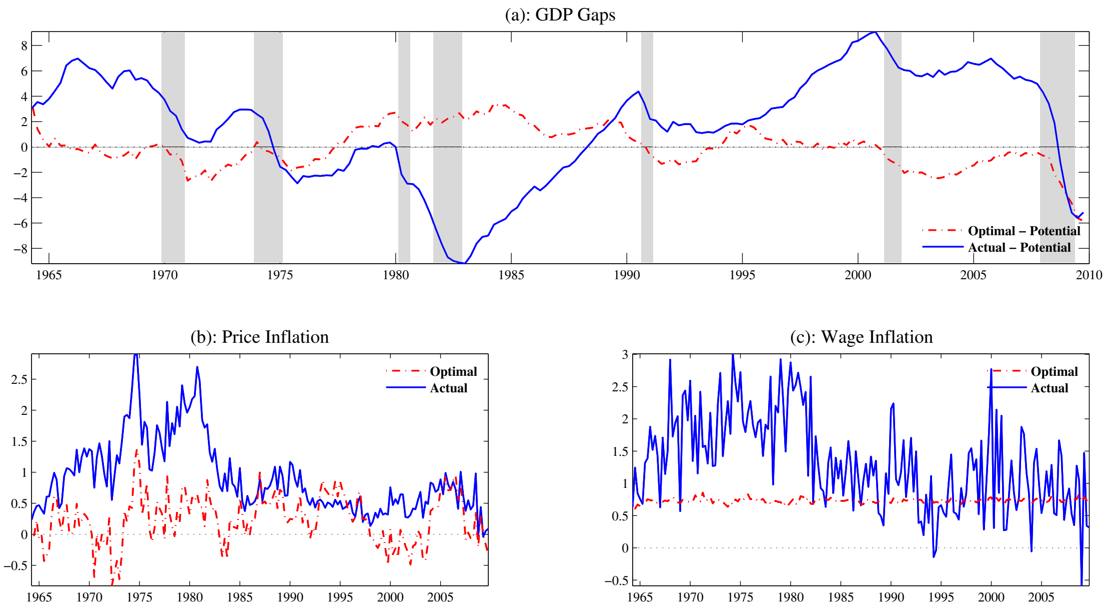

Figure 9: (Lack of) Trinity in the model with financial frictions

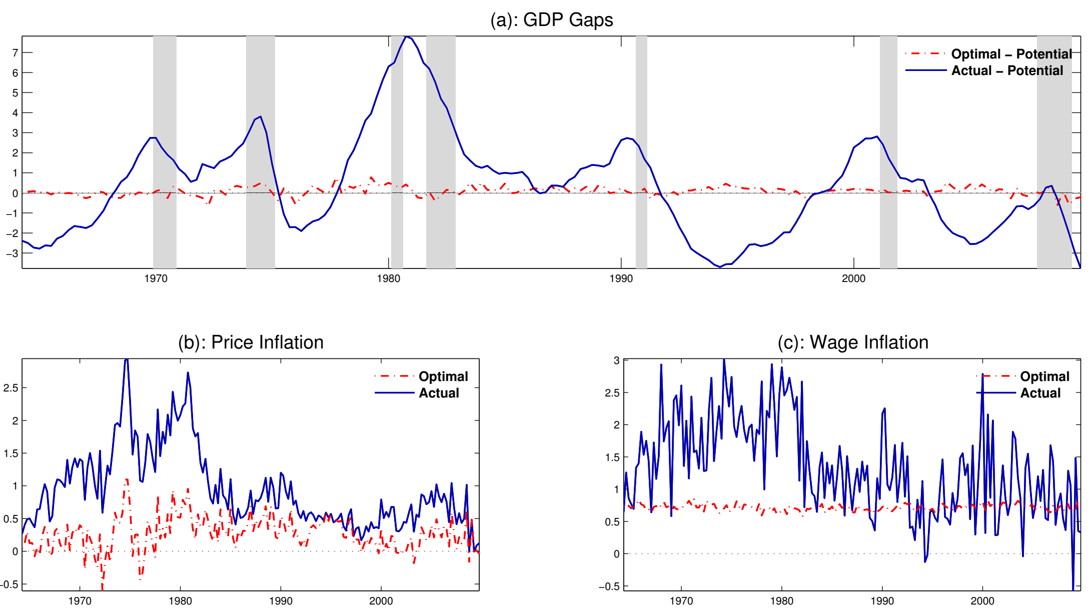

Figure 10: Trinity in the model without financial frictions (JPT (2013))

What is the effect of optimal monetary policy on financial markets? Figure 11 presents the path of spread and asset prices under optimal policy, and the historical interest rate

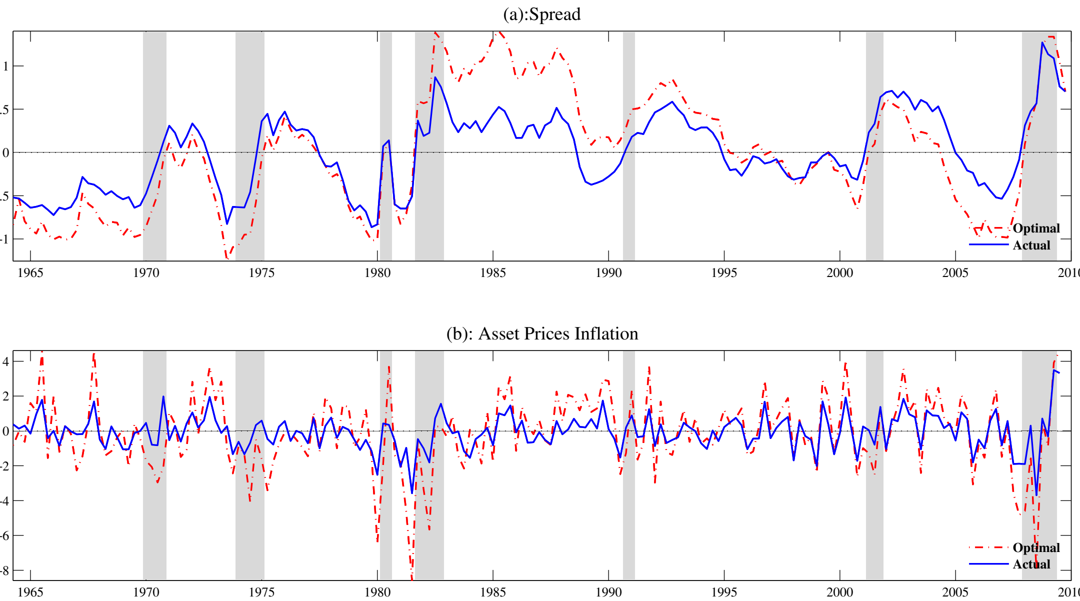

Figure 11: Optimal monetary policy and the financial variables

rule. The blue lines are the variables under Taylor rule monetary policy, while the red dotted lines are computed under the Ramsey optimal monetary policy rule. The paths of financial variables under the optimal and historical rule somewhat track with each other. However, they have been slightly more stationary under the historical interest rate rule. Particularly, actual spread exhibits smaller fluctuations than optimal one during the Great Moderation. Finally, one can conclude that the Fed has not been as successful in stabilizing its macroeconomic objectives by using only the interest rate instrument. An implication of this work is that macroprudential policy would indeed be useful to employ as an active policy tool. This provides a further avenue for future research on macroprudential tools and their impact on macroeconomic stabilization.

V. Conclusion

Financial cycles–the booms and busts in credit and asset prices–have a significant impact on the business cycle. This paper studies channels through which financial frictions affect the frontier of the US economy. Potential output and the output gap are not observable economic variables. Nevertheless, they are crucial variables for policy makers in helping them to gauge the stance of policy, be it in setting interest rates or the size of fiscal balance. Yet, the recent financial crisis has been a sobering experience for economic analysts and policy makers, as it has put in serious doubt previous estimates of potential output and the output gap. Crucially, most estimates of potential output simply focus on the role of mark-up, capital, technology, and sometimes trade variables, ignoring the role of financial variables. In this paper we introduce the missing link of financial variables to standard DSGE models used to analyze the implications for optimal policy making.

This paper analyzes business cycle fluctuations in an environment where financial frictions are a relevant source of inefficiencies. We build our work based on JPT (2013) by extending their NK-DSGE model with a financial accelerator block. We estimate the model using the US macroeconomic and financial data. Inefficiencies stem from different wedges in our economy; more precisely, price and wage rigidities, habit persistence, capital accumulation, financial frictions, and cost-push shocks. According to our estimated model, the fluctuations in the potential output of the economy are mainly driven by the steady state of the wage and price, together with the prevailed leverage ratio, which is a function of the economy's financial condition. We construct a time-varying measure of financial frictions. Both channels of financial frictions–shocks and the accelerator–are present in this measure. We further show that this measure is countercyclical and highly correlated with the default risk spread and proxies of financial condition. Financial frictions enhance the model fit and, consequently, the plausibility of potential output and output gap implied from the model. The evidence provided in this paper shows that the output gap had been positive during the Great Moderation, up to the onset of the financial crisis. Starting from the onset of the crisis, it sharply declined and reached its lowest level, -5.6, in 2009Q2 and bounced back after that. We find that price and wage inflation are significantly less volatile under the optimal policy, but a stabilization policy fails to counteract the fluctuation in output gap, that is to say, in our economy, output-inflation stabilization trade-off is substantial. Therefore a policymaker cannot achieve all stabilization objectives at the same time and has to prioritize stabilizing price and wage inflation, even if it involves undermining output gap stabilization. This trade-off is mainly due to the presence of financial frictions and nominal rigidities. The paths of financial variables under the optimal and historical rule somewhat track with each other. However, spread and asset price inflation have been slightly more stationary under the historical interest rate rule. In particular, actual spreads exhibits smaller fluctuations than the optimal one during the Great Moderation.

We point out the discrepancy between the economy's path that prevails under the historical interest rate rule and under the optimal path. Our conjecture is that this might be due to the underlying differences between the real objectives of the Fed and the one adopted by our model, or the uncertainty. This will further open a discussion for role of macroprudential tools.

Finally, the time variation of parameters in the model, has not been considered, in this chapter, to keep the model tractable. However, financial frictions are likely to change over time, for example, due to the financial liberalization process, as shown by Fuentes Albero (2012). Therefore, modeling of time variation in financial frictions is an important avenue for further research.

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A Appendix - Financial Condition

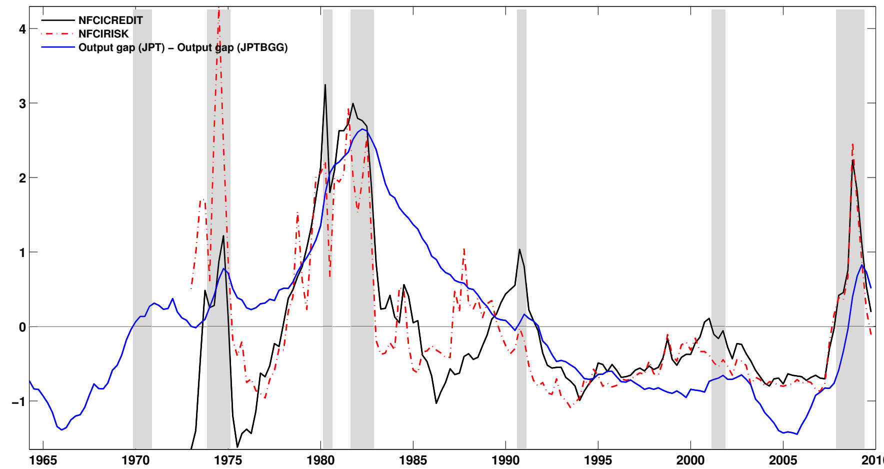

Figure 12: Time-varying financial frictions and financial condition

Table 4: Correlation Between BGG Frictions and Financial Condition

Variable	NFCICREDIT	NFCIRISK
Correlation	0.62	0.53

NFCIRISK: Chicago Fed National Financial Conditions Risk Subindex

NFCICREDIT: Chicago Fed National Financial Conditions Credit Subindex

St. Louis Fed: "The three subindexes of the Chicago Fed's National Financial Conditions Index (NFCI) (risk, credit and leverage) provide a comprehensive weekly update on U.S. financial conditions in money markets, debt and equity markets, and the traditional and "shadow" banking systems. Positive values of the NFCI indicate financial conditions that are tighter than average, while negative values indicate financial conditions that are looser than average."
Source: http://www.chicagofed.org/webpages/research/data/nfci/background.cfm.

B Appendix - Estimation Convergence Diagnostic

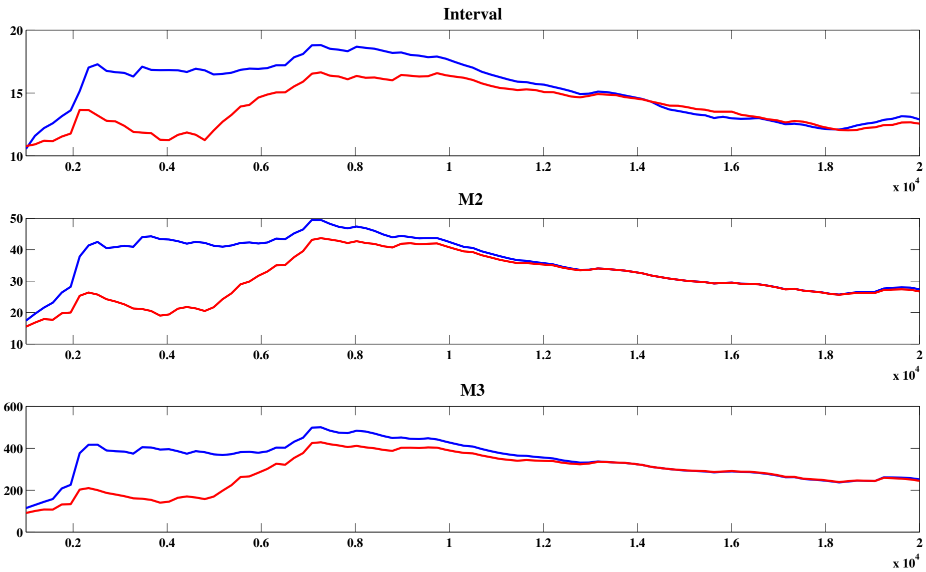

Figure 13: Brooks and Gelman's convergence diagnostic

This figure shows the multivariate convergence statistic of MCMC simulation. The red and blue lines represent within- and between-chain measures. Interval statistic is constructed around parameter mean. M2 statistic is a measure of the variance and M3 is based on third moments. Simulation converges when the red and blue lines get close and settle down. As is clear in the graph, convergence only occurs after 13,000 draws.

C Appendix - Roboustness Check

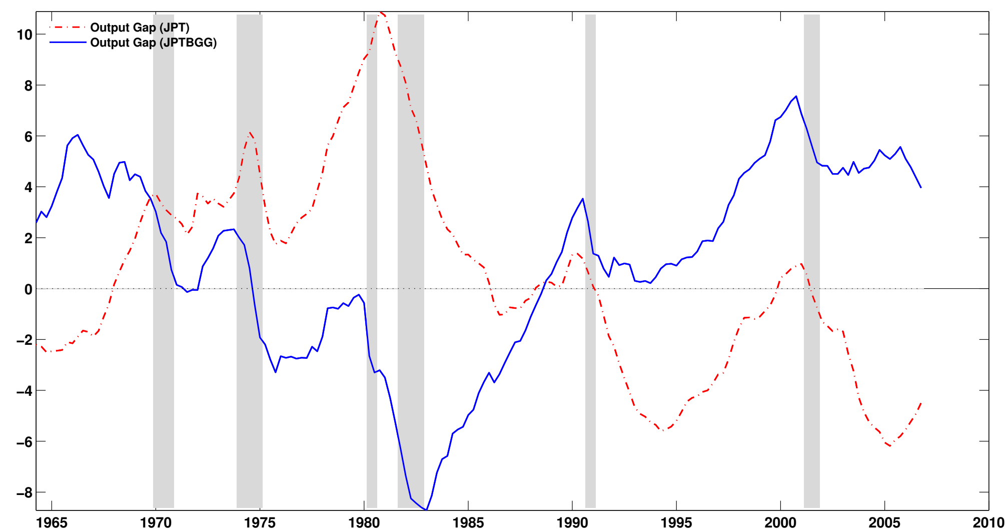

Figure 14: Output gaps implied by models with and without financial frictions, estimated before the crisis

We estimated both JPT and JPTBGG models using a shorter dataset, starting from 1964Q2 up to the recent crisis, 2006Q4. Then we computed the implied output gaps. As is clear from the above figure, the output gap implied by our model behaves robustly.