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UNIVERSITY OF CALIFORNIA
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Essays on Monetary Policy and Inflation in the United States

A Dissertation submitted in partial satisfaction
of the requirements for the degree of

Doctor of Philosophy

in

Economics

by

Venoo Kakar

August 2013

Dissertation Committee:

Dr. Marcelle Chauvet, Chairperson
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To the memory of my Dadi, Dada and Nikri Taya.

To Mamma and Papa.

To Vani.

To Gerald.

ABSTRACT OF THE DISSERTATION

Essays on Monetary Policy and Inflation in the United States

by

Venoo Kakar

Doctor of Philosophy, Graduate Program in Economics
University of California, Riverside, August 2013
Dr. Marcelle Chauvet, Chairperson

This dissertation contributes to two areas of Macroeconomics: (1) welfare effects of infla-

tion and (2) monetary policy and asset prices. The first chapter focuses on examining the

redistributional effects of inflation in the United States in a cash-in-advance economy frame-

work. Most literature on the welfare effects of inflation has largely focused on the aggregate

welfare effects of inflation without much assessment about it's redistributional effects. The

first chapter examines, quantitatively, how different income brackets in the U.S. would be

impacted in terms of consumption and asset positions if long-run inflation were to rise.

The second and third chapters focus on the latter strand of macroeconomics. Re-

cently, central bankers around the world have been debating on what should be the appro-

priate response of monetary policy to large swings in asset prices. In this spirit, chapter

2 examines what would have happened if the Federal Reserve had reacted to stock price

misalignments prior to crashes and major financial crises such as the Great Recession by

extending the standard New Keynesian model to include asset prices. First, the proposed

model is used to estimate the response of monetary policy to the stock market using Bayesian

techniques. We find that the Federal Reserve did not react to U.S. stock market fluctuations

during the Great moderation period. We then undertake a counterfactual experiment in

which we assume that the Federal Reserve targets stock price misalignments in addition to inflation and output gap. Our policy experiment suggests that had the Federal Reserve raised their policy rate in response to rising stock prices, the boom-bust cycle of stock prices would have been substantially reduced and surprisingly, this would not have been associated with a decrease in average output. For example, the exuberance of the dotcom in the late 1990s and the boom in stock prices associated with the housing market in the mid 2000s would have been milder. Further, the severity of the Great Recession in terms of output loss would have been significantly lower had the policy rate been reactive to rising stock prices prior to the crisis. In the wake of the Great Recession, this chapter contributes to the current debate on whether central banks should target asset price misalignments.

The third chapter extends the second chapter to include financial intermediaries to emphasize the role of credit spreads that serve as an important business cycle propagation mechanism. This chapter asks three related questions. First, to what extent has the Federal Reserve adjusted interest rates in response to movements in credit spreads in the past and whether this response has evolved overtime. Second, how does the presence of financial intermediaries that are a source of credit growth, contribute to the fluctuations in the macroeconomy in the face of a monetary policy shock. Third, what effect does a financial shock that tends to increase credit spreads have on macro variables in the economy?

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Chapter 1

On the Redistributional Effects of Long-Run Inflation in a Cash-in-Advance Economy

1.1 Introduction

With over three rounds of quantitative easing by the Federal Reserve to combat the Great Recession of 2007-09, policymakers have raised serious concerns about the impact of the rise in future inflation. Much of the existing literature has discussed how rising inflation impacts the economy as a whole. These studies measure the welfare costs of inflation and find that in general, a rise in long-run inflation reduces social welfare. In particular, households would give up some consumption to achieve zero inflation from a moderate level of inflation. This has been quantified as being less than 1% of consumption which is a fairly small cost. However, this literature has largely ignored the distributional impact of inflation on different income groups. There are only very few studies that have addressed this issue.

For instance, Easterly and Fischer (2001) use polling data for a large number of households in thirty-eight countries and find evidence that inflation is a relatively bigger concern for low-income households than high-income households. They report that the change in low-income households' share of national income, the percent decline in poverty and other measures of improvements in their well-being are negatively correlated with inflation[1]. Amongst the recent quantitative and sectoral studies, Doepke and Schneider (2006) suggest that in the United States, a moderate episode of inflation causes significant redistribution of wealth amongst rich, middle-class and poor households[2]. They find that in a 5 percent inflation experiment, a coalition of rich and old households loses, in present-value terms, between 5.7 and 15.2 percent of GDP. They also find that about two-thirds of this loss accrues to households in the top 10 percent of the wealth distribution. On the winners side, about 75 percent of the total gains in the household sector benefit middle-class households under the age of 45, which receive a gift worth up to 45 percent of mean cohort net worth.

The focus of this paper is to analyze the redistributional effects of long-run inflation among different income brackets in the United States. Our paper builds on previous studies. Similar to Stockman (1981), we introduce money into the model via a cash-in-advance constraint that applies to consumption and investment. However, we extend his representative agent framework to allow for consumer heterogeneity so that we can assess the distributional impact of inflation. In our model, consumer heterogeneity in labor productivity and subjective discount factors is introduced amongst ten income groups. The labor productivity and subjective discount factors are chosen to match the income and

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[1]They examine inflation's effects on the poor in two ways. First, by using a global survey which asked whether individuals think inflation is an important national problem. Second, by assessing the effects of inflation on direct measures of inequality and poverty in various cross-country and cross-time samples.

[2]They emphasize the role of money as a unit of account for assets and liabilities: inflation affects all nominal asset positions, not just cash positions. As a result, they find that even moderate inflation leads to substantial wealth redistribution

wealth distribution in the United States in 2007. As an another interesting feature of the U.S. economy, we introduce progressive tax structure[3] into our model, following Li and Sarte (2004) and Lansing and Guo (1998). Moreover, this modeling assumption ensures that not all households eventually face the highest marginal tax rate simply as a result of economic growth[4]. Long-run inflation, which results from lump-sum monetary injections by the central bank, alters the distribution of disposable income, of wealth and of consumption.

There are only a few studies that analyze the effects of inflation on redistribution of income and wealth in a heterogenous-agent economy. Broadly, these can be categorized into three areas: studies with cash-in advance models Imrohoroglu (1992),Erosa and Ventura (2002)); studies using matching models of money (Molico (2006), Boel and Camera (2009), Chiu and Molico (2010)); and models where money plays a precautionary role (Akyol (2004) and Wen (2010)).

The studies typically differ in the way they introduce money. However, most of these studies do introduce asset(s) so that agents can protect themselves against inflation and money is valued because agents can self-insure against some idiosyncratic shock. In Cash-in-advance (CIA) models, however, agents are not able to switch from holding money to holding assets. Thus, welfare costs could be higher in these models. The welfare losses predicted by these studies differ significantly. For instance, Wen (2010) introduces money as having a precautionary role and reports that to avoid a 10% increase in inflation, agents reduce consumption by 8%. In another study by Erosa and Ventura (2002) in a CIA economy with cash and credit goods, 10% inflation is worth 1.6% consumption[5]. Boel and

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[3]In particular, a statutory tax schedule is said to be progressive whenever the marginal rate exceeds the average rate at all levels of income.

[4]As in Sarte (1997), a progressive tax schedule helps avoid the kind of degenerate equilibrium as analyzed in Becker (1980).

[5]They find that inflation may lead to a substantial concentration in the distribution of wealth and, assuming increasing returns to scale from credit transactions, inflation acts as a regressive consumption tax because low-income agents use mostly cash for trade.

Camera (2009) obtain similar results although they introduce money in a matching model. This suggests that the financial structure of the economy is important in analyzing these effects. For instance, Akyol (2004) reports that 10% inflation maximizes social welfare, whereas another study by Chiu and Molico (2010) reports that 10% inflation is worth 0.6% of average consumption in the U.S.. Imrohoroglu (1992) considers a pure exchange cash-in-advance economy with idiosyncratic endowment risk. He finds that inflation lowers welfare, but the area below the money demand curve, underestimates the welfare cost by several times. Camera and Chien (2011) report that when shocks are sufficiently persistent, moderate inflations can generate welfare gains whereas large inflations are always costly. They offer several insights about the impact of long-run inflation on key macroeconomic variables and suggest that disparities in earlier results can be reconciled with disparities in either the assumed financial structure or in the persistence of shocks. They report that when inflation is generated through lump-sum money creation, higher inflation lowers inequality in disposable income, but it permanently reduces overall income and, hence, depresses aggregate consumption. Therefore, inflation can improve average welfare only if it is capable to sufficiently reduce consumption inequality, which is zero in the efficient allocation.

We find that consumption inequality reduces as inflation increases. In general, we find that as inflation rises, the bottom 60% of the population gains and the top 40% loses. This phenomenon is more pronounced in the bottom 20% of the population. Even though the top 40% of the distribution loses, their consumption patterns do not change as much because of their large wealth holdings.

The rest of the paper is organized as follows: Section 1.2 introduces the model, Section 1.3 discusses the competitive equilibrium, Section 1.4 describes our calibration ex-

ercise, Section 1.5 presents our findings and Section 1.6 concludes. The derivations and tables can be found in Appendix A.

1.2 The Model

1.2.1 Preferences

We consider a model economy which is populated by a continuum of infinitely lived households. The size of the population is normalized to one. The population is divided into s groups where the size of each group i in total population is denoted by $\mu_i \in (0,1)$, for $i \in \{1, 2, ..., s\}$ and $\sum_{i=1}^{s} \mu_i = 1$. The groups differ from each other in terms of labor productivity and rate of time preference. Agents within each group are identical. The labor productivity e_i and discount factor $\beta_i \in (0,1)$ of a type i individual is deterministic and known for each of the s groups. The preferences of a typical agent in group i is given by:

$$\sum_{t=0}^{\infty} \beta_i^t u(c_{i,t}), \tag{1.1}$$

where $c_{i,t}$ is the consumption of an individual in group i at time t. The (period) utility function u (c) is identical for all types of consumers and is given by

$$u(c) = \frac{c^{1-\sigma} - 1}{1 - \sigma} \; if \; \sigma \neq 1; \sigma \geq 0$$

1.2.2 The Agent's Problem

Agents receive total taxable income $y_{i,t}$ which is composed of labor income from work and interest income from savings. The agent can hold two types of assets: real assets denoted by $a_{i,t}$ that give a rate of return r_t and nominal money holding at the beginning of

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period t denoted by $M_{i,t}$. The real asset depreciates at a rate $\delta \in [0, 1]$. There is a progressive tax τ_t which is a function in total taxable income $y_{i,t}$. The properties of the tax schedule are discussed in detail in Section 2.4. The fraction of investment which is subject to the cash-in-advance constraint is controlled by $\psi \in [0, 1]$, as in Dotsey and Sarte (2000). The values $\psi = 0$ and $\psi = 1$ correspond to the Clower (1967) and Stockman (1981) versions, respectively. When $\psi = 0$, the CIA constraint only applies on consumption purchases and when $\psi = 1$, the CIA constraint applies to both consumption and investment. Given a sequence of wages (w_t), rental rate of capital (r_t) and price level (P_t) at time t, the agents' problem is to maximize their discounted lifetime utility, subject to sequences of budget constraints and CIA constraints. Formally, a type i household solves:

$$\max_{\{c_{i,t}, a_{i,t+1}, M_{i,t+1}\}} \sum_{t=0}^{\infty} \beta_i^t u(c_{i,t}) \ where \ \beta_i \in (0, 1) \tag{1.2}$$

s.t.

$$c_{i,t} + \psi[a_{i,t+1} - a_{i,t}] \leq \frac{M_{i,t}}{P_t}, \tag{1.3}$$

and

$$c_{i,t} + a_{i,t+1} - a_{i,t} + \frac{M_{i,t+1}}{P_t} = y_{i,t} - \tau_t(y_{i,t}) + \frac{M_{i,t}}{P_t} + \zeta_t , \tag{1.4}$$

where $w_t e_i + r_t a_{i,t} = y_{i,t}$. The timing of production and trade follows that of the cash-in-advance economy described in Stockman (1981). Each agent allocates his/her income between money and asset holdings. (1.3) represents the liquidity or the CIA constraint which states that the individual must be able to finance his purchases of current consumption and gross investment out of money balances carried over from the previous period plus transfers received at the beginning of the period.

Let real money holdings on period t and real transfers in period t be denoted by $m_{i,t}$ *and* ζ_t, respectively. Let the gross inflation factor be defined as $\pi_{t+1} = P_{t+1}/P_t$. Also, let $\lambda_{i,t}$ *and* $\theta_{i,t}$ denote the Lagrangian multipliers on the CIA and budget constraints, respectively.

Then, the first order conditions of the agents' problem with respect to $c_{i,t}$, $m_{i,t+1}$ and $a_{i,t+1}$ are given by the following, respectively:

$$u'(c_{i,t}) = \lambda_{i,t} + \theta_{i,t} \ , \tag{1.5}$$

$$\beta_i(\lambda_{i,t+1} + \theta_{i,t+1}) = \pi_{t+1}\theta_{i,t} \ , \tag{1.6}$$

$$\beta_i[\psi\lambda_{i,t+1} + \theta_{i,t+1}\{1 + r_{t+1}(1 - \tau'_{t+1}(y_{i,t+1}))\}] = \psi\lambda_{i,t} + \theta_{i,t} \ , \tag{1.7}$$

(1.5) equates the marginal utility of current consumption to the marginal cost of current consumption which is the marginal indirect utility of having an additional real dollar. (1.6) equates the marginal value of having an additional nominal dollar at the beginning of the next period, deflated by the gross inflation factor, to the marginal cost of having that additional dollar. (1.7) equates the marginal benefit of an additional unit of capital which consists of the discounted value of goods it produces next period to the marginal cost of an additional unit of capital. Then, the agents' first order conditions are combined to yield the following Euler equation:

$$\psi u'(c_{i,t}) = [\beta_i\psi - (1-\psi)\frac{\beta_i}{\pi_{t+1}}]u'(c_{i,t+1}) + \beta_i^2\{\frac{1}{\pi_{t+1}}(r_{t+1} - \tau'_{t+1}(y_{i,t+1})r_{t+1} + 1) - \frac{\psi}{\pi_{t+2}}\}u'(c_{i,t+2}). \tag{1.8}$$

This equation governs the law of motion for consumption. The Euler equation can be interpreted as follows: the marginal cost of foregoing one unit of consumption at time t, is equal to the discounted marginal benefit the agent receives from consuming in period t+1 and t+2. The discounted marginal benefit is also deflated by next period's inflation.

1.2.3 Production

Output is produced according to the standard neoclassical production function:

$$Y_t = K_t^\alpha (A_t L_t)^{1-\alpha}, \alpha \in (0,1), \tag{1.9}$$

where Y_t is aggregate output at time t, K_t is aggregate capital at time t, L_t is aggregate labor and A_t is the level of labor augmenting technology at time t. The labor augmenting technology grows at a constant exogenous rate $\gamma \geq 1$, which implies $A_t \equiv \gamma^t$ for all t. The share of capital in total income is given by α. The gross return on physical capital is given by R_t.

Since we assume constant returns to scale in our production, the representative firm maximizes profits as follows:

$$\max_{K_t, L_t} \{F(K_t, A_t L_t) - w_t L_t - R_t K_t\}. \tag{1.10}$$

The solution of the firms problem is then characterized by the following first order conditions:

$$w_t = A_t F_L(K_t, A_t L_t) = (1-\alpha)\frac{Y_t}{L_t}, \tag{1.11}$$

$$R_t = F_K(K_t, A_t L_t) = \alpha \frac{Y_t}{K_t}. \tag{1.12}$$

Depreciation in capital can be viewed as a reduction of rate of return obtained from holding physical capital and thus we have,

$$r_t = R_t - \delta. \tag{1.13}$$

1.2.4 Government Policies

We consider two kinds of policies here: Monetary and Fiscal policy.

Monetary Policy

Let the nominal money supply at period t be given by $\overline{M}_t^s$, real money supply by $m_{i,t}$, price level of output at time t by P_t.

$$\overline{M}_{t+1}^s = g\overline{M}_t^s = \overline{M}_t^s + P_t\zeta_t = P_{t+1}\sum_{i=1}^{s}\mu_i m_{i,t+1} \tag{1.14}$$

Assuming that the central bank issues transfers at the rate of g every period, we have $\overline{M}_{t+1}^s = g\overline{M}_t^s$. Since, money is introduced via lump sum transfers ζ_t at the end of each period, we have, $\overline{M}_{t+1}^s = \overline{M}_t^s + P_t\zeta_t$. The last term equates the nominal value of all real money holdings in period $t+1$, $P_{t+1}\sum_{i=1}^{s}\mu_i m_{i,t+1}$ to the nominal value of the money supply in $t+1$, $\overline{M}_{t+1}^s$.

Fiscal Policy

The government imposes a progressive tax τ_t which is a function in total taxable income $y_{i,t}$ on agent's every period to finance it's expenditure on goods and services in

period t denoted by G_t. The government balances its budget in each period and chooses a tax schedule summarized by the average tax rate (ATR)

$$\text{Tax schedule} = ATR = \eta(\frac{y_{it}}{\gamma^t})^\phi \ with \ 0 \le \eta < 1, \ \phi > 0 \qquad (1.15)$$

just like in Lansing and Guo (1998) and Li and Sarte (2004). Here, the parameters η and ϕ determine the level and the slope of the tax schedule, respectively. With a progressive tax system, households with higher taxable income are subject to higher tax rates, so that

$$\text{Total tax paid} = \tau_t(y_{it}) = y_{it}\eta(\frac{y_{it}}{\gamma^t})^\phi. \qquad (1.16)$$

Once we know our tax schedule, we can discuss the progressivity of the tax structure by calculating the ratio of the marginal and average tax rates.

$$MTR = \tau'_t(y_{it}) = (1+\phi)\eta(\frac{y_{it}}{\gamma^t})^\phi = (1+\phi)ATR.$$

Since the parameter ϕ captures the degree of progressivity of the tax structure, progressive, proportional and regressive tax structures would correspond to $\phi > 0$, $\phi = 0$, $\phi < 0$, respectively. A tax schedule is said to be progressive whenever the marginal tax rate exceeds the average tax rate at all levels of taxable income.

1.3 Competitive Equilibrium

Let $\mathbf{c}_t = (c_{1,t}, c_{2,t}...c_{s,t})$, $\mathbf{a}_t = (a_{1,t}, a_{2,t}...a_{s,t})$ and $\mathbf{m}_t = (m_{1,t}, m_{2,t}...m_{s,t})$ denote a distribution of consumption, capital and money across the s groups at time t, respectively. The competitive equilibrium consists of a sequence of distributions of consumption and

capital, $\{\mathbf{c}_t, \mathbf{a}_t, \mathbf{m}_t\}_{t=0}^{\infty}$, sequences of aggregate inputs, $\{K_t, L_t\}_{t=0}^{\infty}$ and sequences of prices, $\{w_t, r_t, P_t\}_{t=0}^{\infty}$, so that:

1. Given prices $\{w_t, r_t, \pi_{t+1}\}_{t=0}^{\infty}$, the sequences $\{c_{it}, a_{it}, m_{it}\}_{t=0}^{\infty}$ solve each type-i agent's problem.

2. Given prices $\{w_t, R_t\}_{t=0}^{\infty}$ and the aggregate inputs K_t and L_t solve the representative firm's problem.

3. The government's budget is balanced every period.

4. All markets clear every period so that,

   Equilibrium in Labor market:

   $$L_t = \sum_{i=1}^{s} \mu_i e_i = \overline{e} \tag{1.17}$$

   where $\overline{e}$ represents the aggregate level of labor productivity.

   Equilibrium in Capital market:

   $$K_t = \sum_{i=1}^{s} \mu_i a_{i,t} \tag{1.18}$$

   By Walras' Law, the goods market clears.

   Equilibrium in money market:

   $$\overline{M}_{t+1}^{s} = g\overline{M}_t^{s} = \overline{M}_t^{s} + P_t \zeta_t = P_{t+1} \sum_{i=1}^{s} \mu_i m_{i,t+1} \tag{1.19}$$

   Also, the government budget constraint is satisfied:

   $$G_t = \sum_{i=1}^{s} \mu_i \tau_t(y_{i,t}) \tag{1.20}$$

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1.3.1 Balanced Growth Path

This paper focuses on a balanced growth path. A balanced growth path is a competitive equilibrium along which (i) all variables are growing at the constant growth rate $\gamma \geq 1$, and (ii) the real rate of return, r, is constant over time.

Thus,

$$\frac{m_{i,t+1}}{m_{i,t}} = \frac{g}{\pi} = \gamma \tag{1.21}$$

For CIA constraint to be binding along a balanced growth path, we must have $\lambda_{i,t} > 0$ which implies the following:

$$u'(c_{i,t}) - \frac{\beta}{\pi_{t+1}} u'(c_{i,t+1}) > 0$$

The above inequality suggests that for the CIA constraint to be binding, the marginal benefit that the agent receives by increasing consumption at time t by one unit must exceed the marginal cost the agent incurs due to a decrease cash holdings at time t that results in the loss of utility at time t+1 discounted by the rate of time preference and inflation. We can further write the inequality as follows:

$$(\frac{c_{i,t+1}}{c_{i,t}})^\sigma \quad > \quad \frac{\beta_i}{\pi} \ \forall i \tag{1.22}$$

$$or \ \gamma^\sigma \quad > \quad \frac{\beta_i}{\pi} \ \forall i \tag{1.23}$$

For our exercise, we assume that this inequality is binding.

1.4 Calibration

We now assess our model to see the redistributional effects of inflation in the United States. There are three parts to our quantitative exercise that are explained in the

following subsections. We construct a benchmark balanced-growth equilibrium to match some of key features of the U.S. economy. In our analysis, the model period is assumed to be one year.

All benchmark parameter values are summarized in Table 1.1. The benchmark balanced growth equilibrium is constructed to match the following features of the U.S. economy: the capital-output ratio, capital's share of income, average annual growth rate of per-capita GDP, average annual inflation rate, the progressive tax structure and the income and wealth distributions in the United States. More specifically, the labor productivities and the subjective discount factors are calibrated to match the U.S. income and wealth distributions in 2007, using data from the Survey of Consumer Finance as reported in Díaz-Giménez et al. (2011).

Parameter	Description	Value
σ	Inverse of IES	1
γ	Common growth factor	1.018
α	Share of capital income in total output	0.36
δ	Depreciation rate	0.08
$\pi - 1$	Average annual Inflation Rate (1950-07)	0.038
r^*	Equilibrium interest rate	0.04
ψ	Fraction of investment subject to CIA	0.01
β_{10}	Subjective discount factor	0.9948
$1 + \phi$	Ratio of marginal to average tax rate (1960-05)	1.738
η	Scalar in income tax schedule	0.0197

Table 1.1: Benchmark parameters

In our benchmark case, the parameter σ that measures the inverse of the intertemporal elasticity of substitution (IES) in the utility function is set to one. The average annual growth rate of per capita variables $(\gamma - 1)$ is 1.8%, which is the annual growth rate of real per-capita GDP in the United States over the period 1950-2007. The share of capital income in total output (α) is 1/3. The depreciation rate is calibrated so that the capital-

output ratio is 3.0. The average annual inflation rate $(\pi - 1)$ is 3.8% which is calculated using the Consumer Price Index (CPI) over the period 1950-2007 . Dotsey and Sarte (2000) mention that for the US and most OECD economies, the fraction of investment subject to the Cash-in-advance constraint (ψ) is probably close to zero because of high financial sophistication. In our benchmark case, we assume a very small value of (ψ)=0.1. Empirical findings show that a higher ψ is empirically plausible supported by a significant increase in consumer credit in the last two decades (Ludvigson (1999)). Also,the average cash-to-assets ratio for U.S. industrial firms more than doubled from 1980 to 2006 that could help firms to pay off their debt entirely in cash (Bates et al. (2009)). Later, we do a sensitivity analysis by considering higher values of ψ corresponding to lower degrees of financial sophistication.

Based on the data reported in Table 5 of Díaz-Giménez et al. (2011), we first divide the U.S. income distribution into ten groups (namely, 1-5%, 5-10%, 10-20%, 20-40%, 40-60%, 60-80%, 80-90%, 90-95%, 95-99%) implying s=10. The bottom 1% of the distribution is discarded because the average income for this group turns out to be negative. The subjective discount factors are chosen so as to match the share of total income held by each group[6]. In other words, the subjective discount factors are chosen so as to match the Lorenz curve for income in the 2007 Survey of Consumer Finances (SCF) sample in Díaz-Giménez et al. (2011). After the subjective discount factors are determined, we then choose the labor productivities so as to match the share of total wealth owned by the ten income groups. The data are again taken from Table 5 of Díaz-Giménez et al. (2011). This procedure is further discussed in the Appendix A.

The ratio of marginal to average tax rates $(1+\phi)$ are computed between the period 1950-2005[7] The average of the degree of progressivity $(1 + \phi = 1.738)$ for the specified time

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[6]This involves solving a set of nonlinear equations for the subjective discount factors. The technical details can be found in the appendix.

[7]Feenberg and Coutts (1993) and Taxsim are the sources used for computing the degree of progressivity.

period is used in our exercise. The scalar in income tax schedules η are calibrated to match the average tax rate (ATR) of 13.8% for the same time period.

1.5 Findings

This section reports findings regarding the redistributional effects of inflation on consumption, disposable income and cash holdings among the ten income groups as well as overall inequality. In order to do this, we consider a number of counterfactual experiments in which the long-run inflation rate is changed.

1.5.1 Benchmark results

Table A.1 summarizes the Gini coefficients for income, wealth, cash-holdings and consumption as suggested by our benchmark model[8] vs. the data. The data is taken from Díaz-Giménez et al. (2011) and Wen (2010). We find that our model is able to match the Gini coefficient of income close to the one found in the data. As for the wealth distribution, the model predicts a more equal distribution as compared to that observed in the data. Since, we have ignored the analysis for the bottom 1% of the population in our study due to their average income being negative[9], our prediction of a more equal distribution for both income and wealth may be a direct result of having incomes as strictly positive. Table A.2 reports the share of wealth held as money for the ten income brackets. We find that as income increases, households tend to hold less money as a fraction of their total wealth. The bottom 5% holds 14% of their total wealth as money as compared to the top 1%, who hold only 6%[10]. This finding is also supported by the Flow of Funds data for the household sector

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[8]These results correspond to the long-run inflation rate of 3.8% for the United States.

[9]In the actual data, the average earnings of the bottom 1% of the distribution are negative

[10]Note, however that if we consider aggregate money holdings for each income bracket, they are obviously much lower for the bottom 5% and much higher for the top 1%, see Table A.6.

that contain a detailed breakdown for the assets and liability positions for the households.

Following Stockman (1981), we can recall that since money has a negative rate of return during inflation, agents have a higher opportunity cost of holding money. This reduces the willingness to hold money. In other words, the incentive to hold money beyond the mere transaction need for consumption and investment declines. Due to the cash-in- advance constraint on consumption and investment, in periods of inflation, the households would decrease both consumption and lower investment. The real purchases of both consumption and investment goods fall with decreased money holdings at higher rates of inflation since money is more costly to hold. This results in the net return from investment to be lower in utility terms. Inflation acts as tax on investment.

Our main results are analyzed in the following subsections. We perform five counterfactual experiments in which we change the long-run inflation rate from 3.8% to 1.8%, 2.8%, 4.8%, 5.8% and 8.8%. We then report the redistributional effects for disposable income, consumption and money and analyze our sensitivity experiments.

1.5.2 Redistribution of Disposable Income, consumption and money

We find that disposable income[11] inequality, consumption inequality and inequality in cash-holdings decreases as inflation rises. Tables A.3, A.5 and A.6 provide evidence. The rich hold more cash than the poor and so inflation is more likely to hurt the rich than the poor in terms of cash holdings. This is evident in Table A.6. The bottom 5% hold 0.15 worth of real money balances and the top 1% hold 13.43. Since, inflation is a direct result the lump-sum money creation that is distributed evenly among households, the bottom 60% gains and top 40% loses in terms of cash holdings as inflation rises. This results in making

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[11]Disposable income is measured as income plus transfers less taxes.

the distribution of cash holdings more even, as reflected in the lower Gini coefficient with higher inflation.

Consumption inequality reduces as inflation increases however, we find that overall consumption falls. Since inflation rate of 3.8% is our benchmark for inflation, we look at both deflationary and inflationary episodes. Since, consumption is financed by money holdings only in a cash-in-advance framework, we find that once again the bottom 60% gain and top 40% lose with inflation. With reference to Tables A.4 and A.7, we can talk discuss who loses and wins from these episodes of an increase in long-run inflation. Even though the top 40% of the distribution loses, their consumption patterns do not change as much because of their large wealth holdings. We find a similar result for the net disposable income. The Lorenz curves for disposable income, consumption and money holdings are depicted in Figures A.1, A.2, A.3, and A.4. In order to make the curves visible, we consider hyperinflationary episodes. We find that with rising inflation, inequality in disposable income, consumption and money holdings fall. The lorenz curves move towards the line of perfect equality. Our results are similar to Doepke and Schneider (2006) who find that the losers in the economy are the old and rich households at the top of the distribution. The winners are the young middle class that have substantial fixed-rate mortgage positions and the poor who have a sizeable amount of debt[12].

1.5.3 Robustness Checks

The third part of our quantitative exercise is to assess whether our results are sensitive to changes in three factors: the inverse of intertermporal elasticity of substitution, σ; the fraction of investment subject to the cash-in-advance constraint, ψ; and hyperinfla-

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[12]They also report similar results for having surprise inflation. In order to compare our results with Doepke and Schneider (2006), we only focus on the experiments when inflation is fully anticipated

tionary episodes. The results are depicted in Tables A.8, A.9 and A.10. We consider $\sigma = 1$ as our benchmark case and for our sensitivity analysis, we change σ to 0.5 and 1.5. Let's consider an increase in the value of σ that would lower the intertemporal elasticity of substitution. Ceteris paribus, each consumer would want to have less savings. The reduction in savings would be larger for the rich relative to the poor. Also, as aggregate savings decrease the real rate of interest would adjust in order to keep the capital to output ratio constant. This would encourage the rich to increase asset holdings. We find that overall, with an increase in inflation, these two effects cancel out. However, we do observe the distribution becoming more equal with inflation in which case the first effect outweighs the latter.

We consider $\psi = 0.01$ as our benchmark case and for our sensitivity analysis, we change ψ to 0.1, 0.2 and 0.3. These values do not affect our results. Consumption inequality still falls with inflation even if the degree of financial sophistication in the economy is lower. This should be the case as our model does not assume any access to sophisticated credit or financial markets. We consider inflation rates that are 10%, 20%, 30%, 40%, and 50% above the benchmark inflation rate of 3.8% Our results are robust to changes in the inverse of intertemporal elasticity of substitution (σ), the fraction of investment subject to the CIA constraint (ψ) and the hyperinflationary episodes. We also check the case when transfers are zero and find that the Gini coefficient for disposable income change by less than 0.1% when inflation rises by 5%. Thus, in our model, the redistributional effects are driven by the lump-sum transfers each period that result in inflation.

1.6 Conclusion

This paper contributes to the scant literature on the redistributional effects of inflation in the U.S. economy. The model presented in this paper is an extension of the

standard cash-in-advance model by Stockman (1981). Our model allows for heterogeneity in the rate of time preference and labor productivities. We use this heterogeneity to match the income and wealth distributions in the U.S. among different income groups. In our model, the cash-in-advance constraint on consumption and investment is introduced. We find that a rise in inflation benefits the bottom 60% of the distribution and hurts the top 40% in terms of consumption, welfare, cash-holdings and disposable income. We also acknowledge that contrasting our model with other studies, the results presented in this paper depend on the financial structure of the economy.

Appendix A

Appendix

A.1 Results

Gini Coefficients		
	Model	Data
Income	0.56	0.575
Wealth	0.67	0.816
Cash-Holdings	0.467	-
Consumption	0.465	0.28

Table A.1: Benchmark Results; Data Sources: Díaz-Giménez et al. (2011) and Wen (2010)

	Model
Bottom 1-5%	0.1481
5-10%	0.3229
10-20%	0.2369
20-40%	0.2639
40-60%	0.2735
60-80%	0.2347
80-90%	0.2212
90-95%	0.1452
95-99%	0.0922
Top 99-100%	0.0632

Table A.2: Share of wealth held as money

Income groups	$\pi = 1.018$	$\pi = 1.028$	$\pi = \mathbf{1.038}$	$\pi = 1.048$	$\pi = 1.058$	$\pi = 1.088$
Bottom 1-5%	0.136	0.146	0.155	0.165	0.174	0.201
5-10%	0.199	0.208	0.217	0.226	0.234	0.259
10-20%	0.279	0.287	0.296	0.304	0.312	0.334
20-40%	0.463	0.469	0.475	0.482	0.488	0.506
40-60%	0.743	0.747	0.751	0.754	0.758	0.768
60-80%	1.161	1.160	1.160	1.159	1.159	1.158
80-90%	1.712	1.706	1.700	1.694	1.688	1.673
90-95%	2.351	2.339	2.326	2.314	2.303	2.270
95-99%	4.105	4.075	4.045	4.016	3.988	3.907
Top 99-100%	13.396	13.272	13.151	13.032	12.916	12.508
Aggregate	24.484	24.413	24.280	24.150	24.023	23.661
Gini_C	0.474	0.469	0.465	0.460	0.455	0.443

Table A.3: Consumption Inequality

Gain/loss in consumption					
Income groups	$\pi = 1.018$	$\pi = 1.028$	$\pi = 1.048$	$\pi = 1.058$	$\pi = 1.088$
Bottom 1-5%	-12.38	-6.09	6.03	11.93	29.07
5-10%	-8.33	-4.14	4.05	8.01	19.56
10-20%	-5.57	-2.76	2.7	5.36	13.1
20-40%	-2.69	-1.32	1.32	2.6	6.38
40-60%	-0.97	-0.47	0.47	0.94	2.34
60-80%	0.08	0.04	-0.04	-0.07	-0.13
80-90%	0.69	0.34	-0.33	-0.67	-1.57
90-95%	1.06	0.52	-0.51	-1.01	-2.42
95-99%	1.47	0.73	-0.71	-1.41	-3.4
Top 99-100%	1.86	0.92	-0.9	-1.78	-4.88

Table A.4: Percentage change in consumption from Benchmark

Income groups	$\pi = 1.018$	$\pi = 1.028$	$\pi = \mathbf{1.038}$ Benchmark	$\pi = 1.048$	$\pi = 1.058$	$\pi = 1.088$
Bottom 1-5%	0.155	0.168	0.179	0.191	0.202	0.236
5-10%	0.213	0.225	0.237	0.248	0.26	0.294
10-20%	0.304	0.317	0.328	0.340	0.351	0.385
20-40%	0.498	0.513	0.524	0.535	0.547	0.581
40-60%	0.798	0.814	0.825	0.837	0.848	0.882
60-80%	1.257	1.275	1.286	1.298	1.309	1.343
80-90%	1.859	1.880	1.892	1.903	1.915	1.949
90-95%	2.639	2.664	2.676	2.687	2.698	2.732
95-99%	4.842	4.877	4.890	4.901	4.912	4.946
Top 99-100%	16.704	16.749	16.787	16.798	16.808	16.841
Gini_DY	0.491	0.486	0.482	0.478	0.474	0.461

Table A.5: Disposable Income Inequality

Income groups	$\pi = 1.018$	$\pi = 1.028$	$\pi = \mathbf{1.038}$ Benchmark	$\pi = 1.048$	$\pi = 1.058$	$\pi = 1.088$
Bottom 1-5%	0.137	0.147	0.157	0.166	0.175	0.202
5-10%	0.198	0.209	0.218	0.226	0.235	0.260
10-20%	0.279	0.289	0.297	0.305	0.313	0.336
20-40%	0.462	0.471	0.478	0.484	0.490	0.508
40-60%	0.742	0.750	0.754	0.757	0.761	0.771
60-80%	1.161	1.665	1.166	1.165	1.165	1.164
80-90%	1.712	1.7152	1.709	1.703	1.698	1.682
90-95%	2.361	2.36	2.348	2.336	2.324	2.290
95-99%	4.147	4.134	4.106	4.077	4.049	3.967
Top 99-100%	13.653	13.536	13.439	13.320	13.203	12.867
Gini_m	0.476	0.471	0.467	0.462	0.458	0.445

Table A.6: Inequality in Cash Holdings

Income groups	$\pi = 1.038$	$\pi = 1.088$
Bottom 1-5%	0.7848	0.8885
5-10%	0.9383	1.0206
10-20%	1.0845	1.1503
20-40%	1.3717	1.4124
40-60%	1.7197	1.7377
60-80%	2.1270	2.1240
80-90%	2.5686	2.5467
90-95%	2.9665	2.9294
95-99%	3.8295	3.7630
Top 99-100%	6.7055	6.5562
Total welfare	24.0961	24.1288

Table A.7: Welfare analysis

A.2   Sensitivity Analysis

Gain/loss in consumption (% change from benchmark)					
	Net Inflation Rate $(\pi - 1)$ (Above benchmark)				
Income Groups	10%	20%	30%	40%	50%
Bottom 1-5%	56.22	102.82	142.16	176.76	207.06
5-10%	37.98	69.24	95.71	119.01	139.45
10-20%	25.56	46.47	64.16	79.83	93.58
20-40%	12.71	22.86	31.44	39.17	45.98
40-60%	4.95	8.6	11.66	14.62	17.24
60-80%	0.18	-0.12	-0.41	-0.38	-0.32
80-90%	-2.57	-5.19	-7.45	-9.12	-10.56
90-95%	-4.21	-8.19	-11.59	-14.27	-16.58
95-99%	-6.12	-11.66	-16.38	-20.24	-23.56
Top 99-100%	-7.91	-14.89	-20.9	-25.87	-30.14
Gini_C	0.4229	0.3878	0.3579	0.3323	0.31

Table A.8: Sensitivity Analysis: Hyperinflation

$\sigma = \mathbf{1.5}$	$\pi = 1.018$	$\pi = 1.028$	$\pi = \mathbf{1.038}$ _Benchmark_	$\pi = 1.048$	$\pi = 1.058$	$\pi = 1.088$
Gini_C	0.4751	0.4704	0.4658	0.4612	0.4567	0.4437
Gini_DY	0.4913	0.4868	0.4825	0.4782	0.474	0.4617
Gini_Y	0.5595	0.5595	0.5595	0.5595	0.5595	0.5595
Gini_W	0.6701	0.6701	0.6701	0.6701	0.6701	0.6701
$\sigma = \mathbf{0.5}$	$\pi = 1.018$	$\pi = 1.028$	$\pi = \mathbf{1.038}$ _Benchmark_	$\pi = 1.048$	$\pi = 1.058$	$\pi = 1.088$
Gini_C	0.4734	0.4687	0.464	0.4595	0.455	0.4421
Gini_DY	0.49	0.4871	0.4827	0.4785	0.4743	0.4621
Gini_Y	0.5595	0.5595	0.5595	0.5595	0.5595	0.5595
Gini_W	0.6701	0.6701	0.6701	0.6701	0.6701	0.6701

Table A.9: Sensitivity Analysis: changing the inverse of the intertemporal elasticity of substitution, σ

Income groups	$\psi = 0.1$	$\psi = 0.2$	$\psi = 0.3$
Bottom 1-5%	0.136	0.156	0.157
5-10%	0.199	0.217	0.218
10-20%	0.279	0.296	0.297
20-40%	0.463	0.476	0.477
40-60%	0.743	0.751	0.753
60-80%	1.161	1.16	1.162
80-90%	1.712	1.699	1.703
90-95%	2.351	2.325	2.330
95-99%	4.105	4.042	4.048
Top 99-100%	13.396	13.141	13.136
Gini_C	0.474	0.464	0.464

Table A.10: Sensitivity Analysis with limited or ineffectual credit markets

A.3   Figures

Disposable Income

Lorenz Curves for Disposable Income
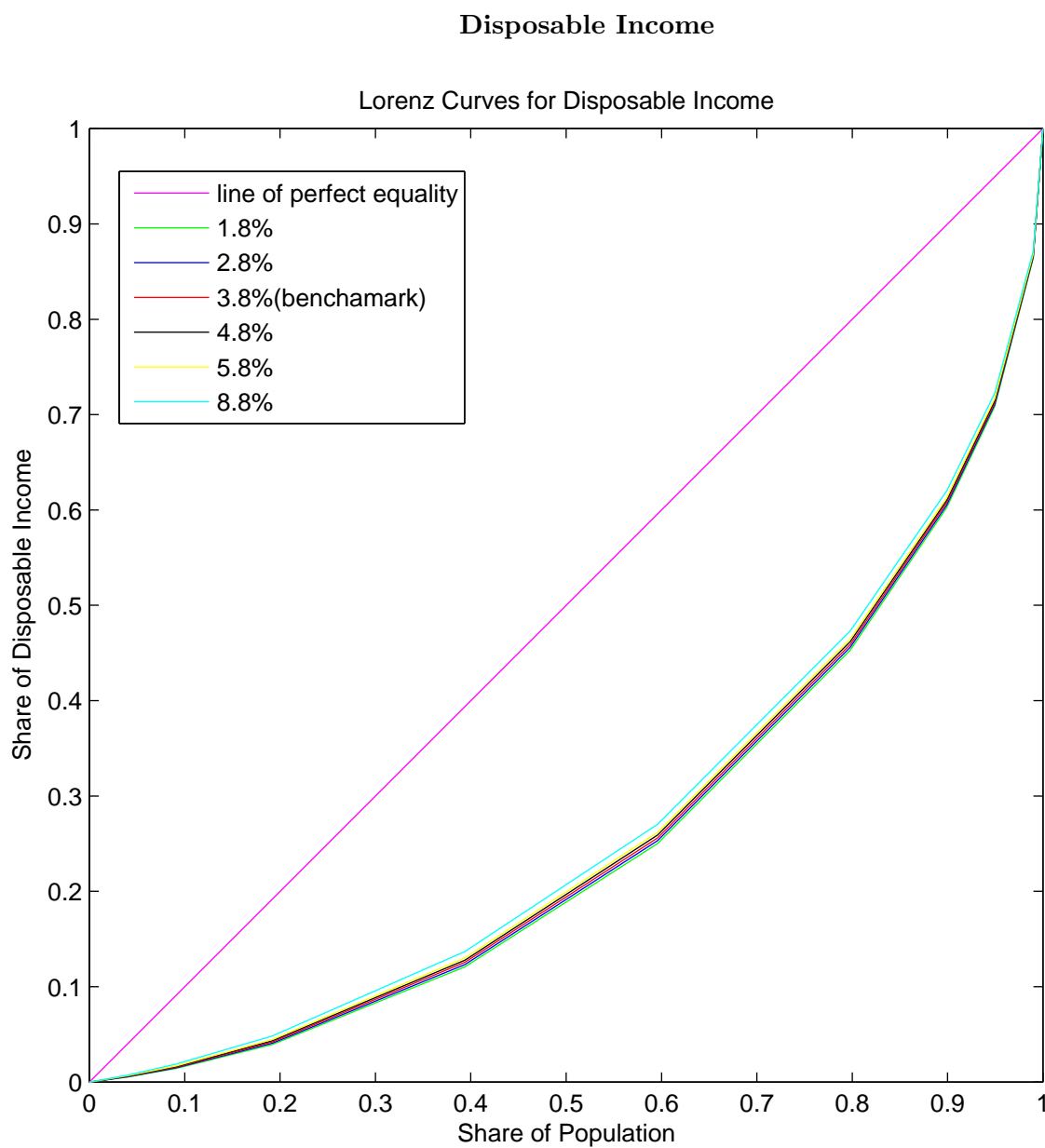
Figure A.1: Lorenz Curves for Disposable Income

Disposable Income with Hyperinflation
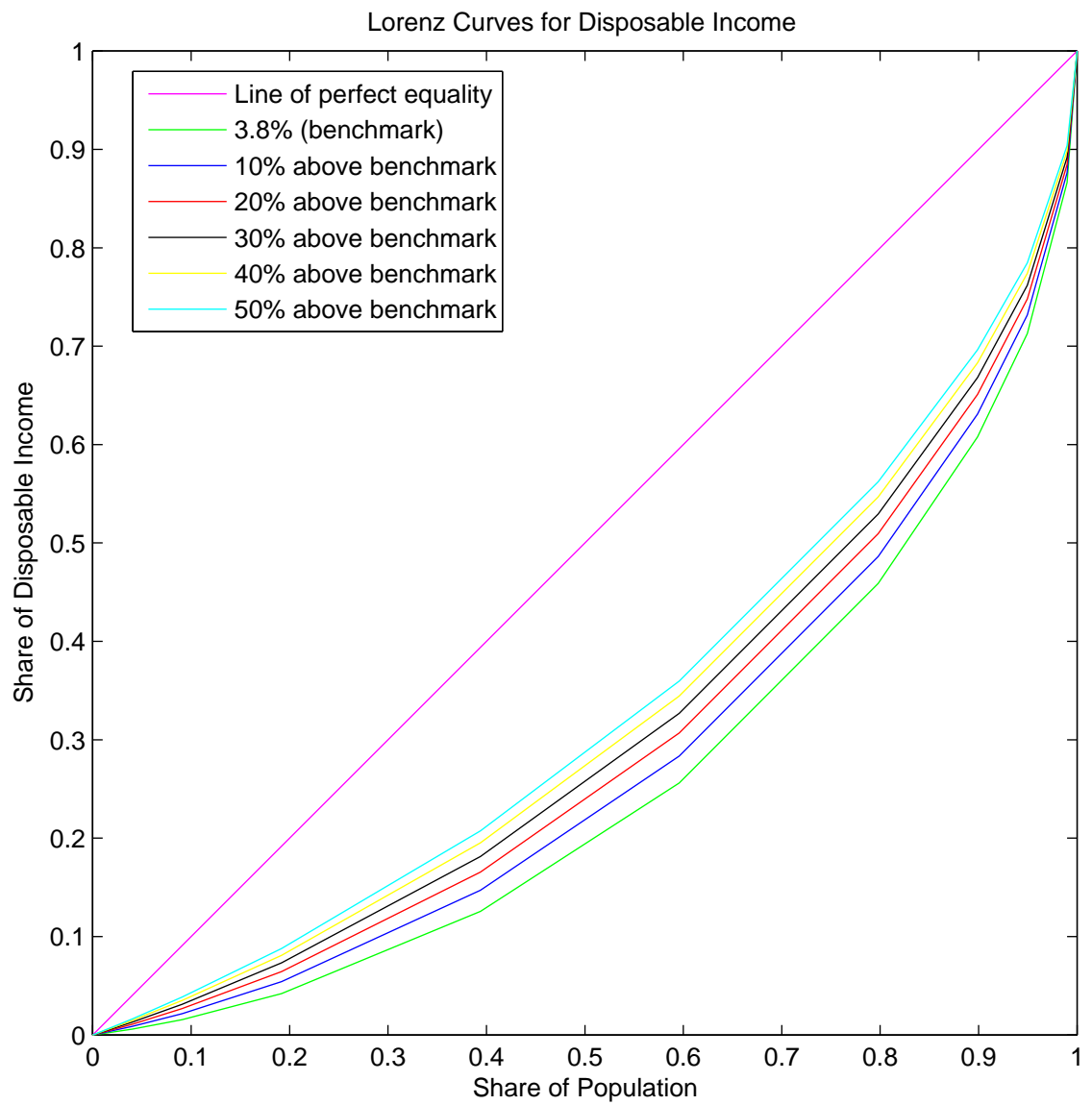
Figure A.2: Lorenz Curves for Disposable Income
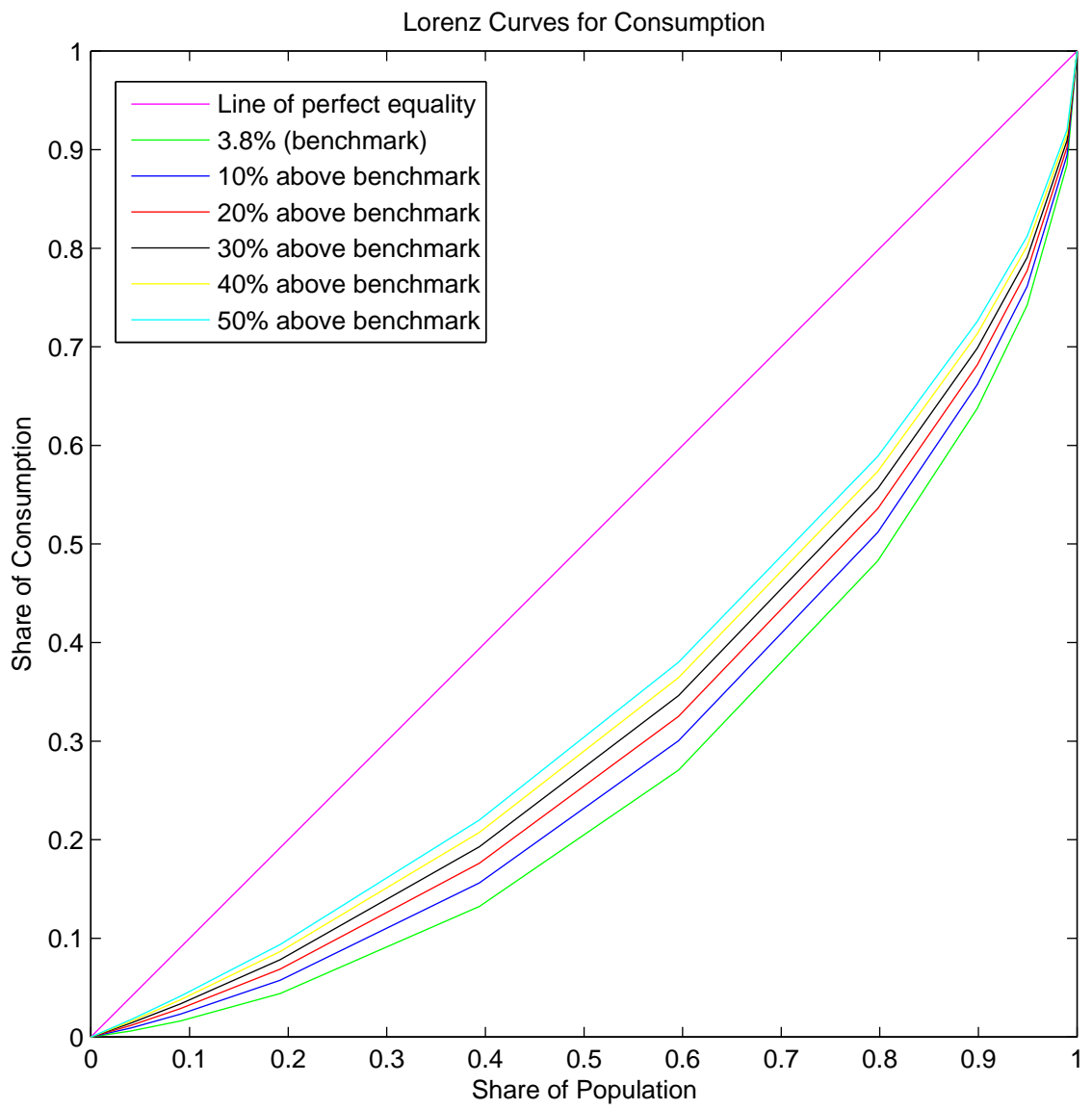
Consumption

Figure A.3: Lorenz Curves for consumption

Money
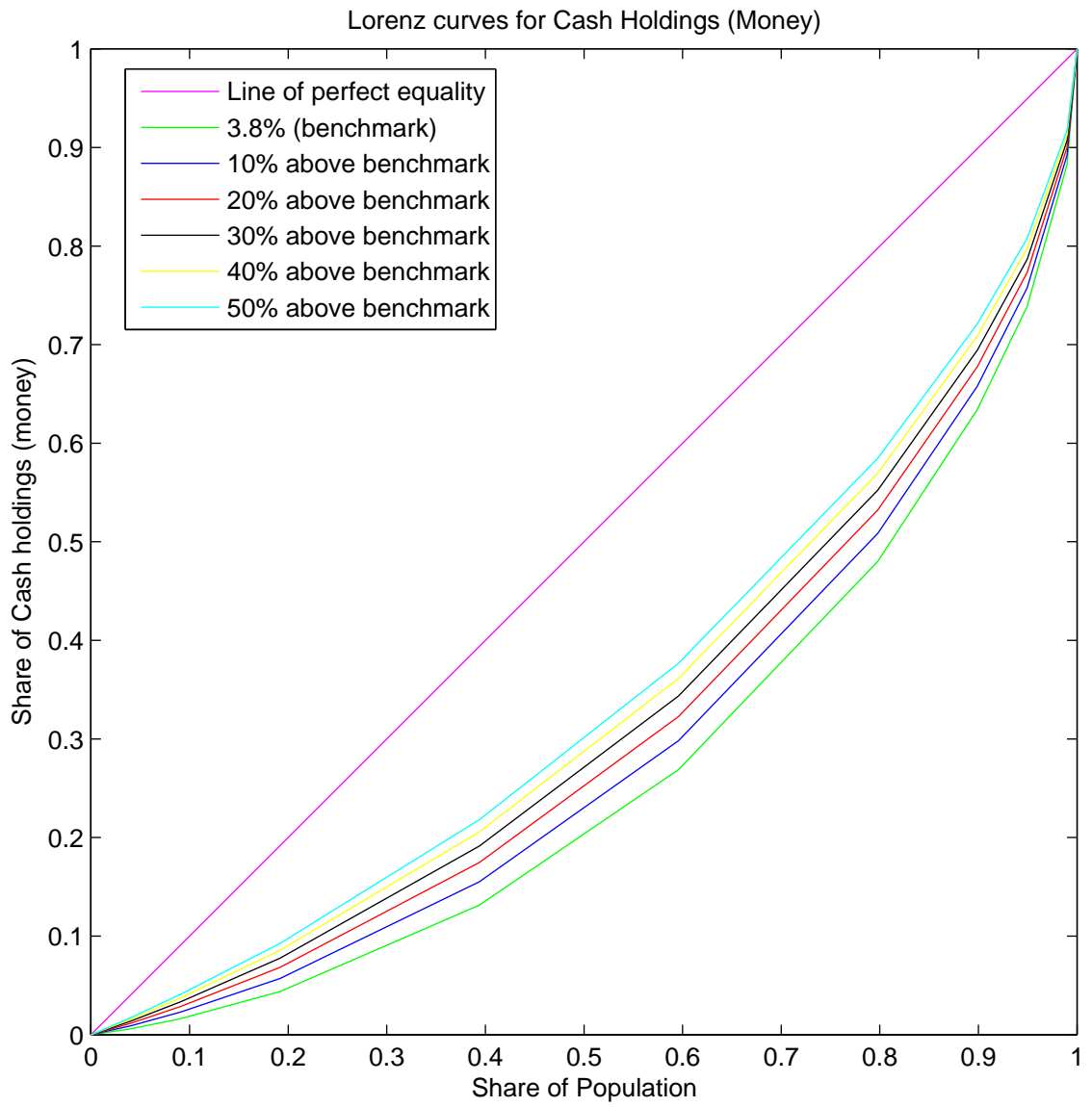
Figure A.4: Lorenz Curves for money holdings

A.4   Kuhn-Tucker Conditions:

The agents problem can be re-written in real terms as:

$$\max_{(c_{i,t}, a_{i,t+1}, m_{i,t+1})} \sum_{t=0}^{\infty} \beta_i^t u(c_{i,t}) \, where \, \beta_i \in (0,1) \tag{A.1}$$

s.t.

$$c_{i,t} + \psi[a_{i,t+1} - a_{i,t}] \leq m_{i,t} \, where \, \psi, \delta \in [0,1] \tag{A.2}$$

and

$$c_{i,t} + a_{i,t+1} - a_{i,t} + \pi_{t+1} m_{i,t+1} = y_{i,t} - \tau_t(y_{i,t}) + m_{i,t} + \zeta_t \tag{A.3}$$

For the derivation of the first order conditions consider the Lagrangian:

$$\begin{aligned} L \quad = \quad & \sum_{t=0}^{\infty} \beta_i^t [u(c_{i,t}) + \lambda_{i,t} \{m_{i,t} - c_{i,t} - \psi(a_{i,t+1} - a_{i,t})\} + \\ & \theta_{i,t} \{y_{i,t} - \tau_t(y_{i,t}) + m_{i,t} + \zeta_t - c_{i,t} - a_{i,t+1} + a_{i,t} - \pi_{t+1} m_{i,t+1}\}] \end{aligned}$$

Assuming $c_{i,t} > 0; \lambda_{i,t} \geq 0; \theta_{i,t} > 0; m_{i,t+1} \geq 0$

$c_{i,t}$:

$$u'(c_{i,t}) = \lambda_{i,t} + \theta_{i,t}$$

$m_{i,t+1}$:

$$\theta_{i,t} \pi_{t+1} - \beta_i(\lambda_{i,t+1} + \theta_{i,t+1}) = 0 \tag{A.4}$$

$a_{i,t+1}$:

$$\psi\lambda_{i,t} + \theta_{i,t} - \beta_i[\psi\lambda_{i,t+1} + \theta_{i,t+1}\{r_{t+1}(1 - \tau'(y_{i,t})) + 1\}] \leq 0$$

$$and \ a_{i,t+1}[\psi\lambda_{i,t} + \theta_{i,t} - \beta_i[\psi\lambda_{i,t+1} + \theta_{i,t+1}\{r_{t+1}(1 - \tau'(y_{i,t})) + 1\}] = 0 \tag{A.5}$$

$\lambda_{i,t}$:

$$m_{i,t} - c_{i,t} - \psi(a_{i,t+1} - a_{i,t}) \geq 0 \quad and \ \lambda_{i,t}[m_{i,t} - c_{i,t} - \psi(a_{i,t+1} - a_{i,t})] = 0 \tag{A.6}$$

$\theta_{i,t}$:

$$y_{i,t} - \tau_t(y_{i,t}) + m_{i,t} - c_{i,t} - a_{i,t+1} + a_{i,t} - \pi_{t+1}m_{i,t+1} + +\zeta_t = 0 \tag{A.7}$$

If money is held, we have:

$$\theta_{i,t} = u'(c_{i,t}) - \lambda_{i,t} = \frac{\beta_i}{\pi_{t+1}}u'(c_{i,t+1}) \tag{A.8}$$

Combining the above equations we get the following, Euler equation:

$$\psi u'(c_{i,t}) = [\beta_i\psi - (1-\psi)\frac{\beta_i}{\pi_{t+1}}]u'(c_{i,t+1}) + \beta_i^2\{\frac{1}{\pi_{t+1}}(r_{t+1} - \tau_t'(y_{i,t+1})r_{t+1} + 1) - \frac{\psi}{\pi_{t+2}}\}u'(c_{i,t+2})$$

For the cash-in-advance constraint to be binding, we must have $\lambda_{i,t} > 0$; which implies

$$u'(c_{i,t}) - \frac{\beta}{\pi_{t+1}}u'(c_{i,t+1}) > 0 \tag{A.9}$$

The above condition can be interpreted as the following: For the CIA to be binding we must have, the marginal benefit (achieved from increasing consumption by one unit today) exceed the marginal cost to the agent (due to the discounted value of the decrease in the money holdings by π_{t+1} units today).

A.5 Aggregation:

Aggregating the individual budget constraints over the entire economy we get,

$$\sum_{i=1}^{s}\mu_i[c_{i,t} + a_{i,t+1} - a_{i,t} + \pi_{t+1}m_{i,t+1}] \leq \sum_{i=1}^{s}\mu_i[y_{i,t} - \tau_t(y_{i,t}) + m_{i,t}] + \zeta_t \qquad (A.10)$$

$$\sum_{i=1}^{s}\mu_i[c_{i,t} + a_{i,t+1} - a_{i,t} + \pi_{t+1}m_{i,t+1}] \leq \sum_{i=1}^{s}\mu_i(w_te_i + r_ta_{i,t}) - \sum_{i=1}^{s}\mu_i\tau_t(y_{i,t}) + \sum_{i=1}^{s}\mu_im_{i,t} + \zeta_t$$
$$(A.11)$$

Using market clearing conditions and re-writing we get back the goods market clearing condition:

$$C_t + K_{t+1} - (1-\delta)K_t + G_t = Y_t \qquad (A.12)$$

A.6 Transformed variables

Consider the following transformed variables:

$$\widehat{c}_i = \frac{c_{i,t}}{\gamma^t}; \widehat{a}_i = \frac{a_{i,t}}{\gamma^t}; \widehat{m}_i = \frac{m_{i,t}}{\gamma^t}; \widehat{w} = \frac{w_t}{\gamma^t}; \widehat{y}_i = \frac{y_{i,t}}{\gamma^t}; R = R_t; r = r_t; \pi = \pi_t \ ; \frac{\zeta_t}{\gamma^t} = \zeta \forall t \quad (A.13)$$

Also, rewriting the tax function from the text we have,

$$Tax\ schedule = ATR = \eta(\frac{y_{it}}{\kappa\gamma^t})^\phi = \eta(\frac{\widehat{y}_i}{\kappa})^\phi with\ 0 \leq \eta < 1, \ \phi > 0, \kappa > 0 \qquad (A.14)$$

$$Total\ tax\ paid = \tau_t(y_{it}) = y_{it}\eta(\frac{y_{it}}{\kappa\gamma^t})^\phi \qquad (A.15)$$

gives

$$MTR = \tau_t'(y_{it}) = (1+\phi)\eta(\frac{\widehat{y_i}}{\kappa})^\phi = (1+\phi)ATR \qquad (A.16)$$

Rewriting the first order conditions in terms of the transformed variables, we get 3 equations in 3 unknowns $(\widehat{m}_i, \widehat{c}_i, \widehat{a}_i)$:

$$\widehat{m}_i - \widehat{c}_i - \psi(\gamma-1)\widehat{a}_i = 0$$

$$\widehat{y}_i - \widetilde{\tau}(\widehat{y}_i) + (1-\pi\gamma)\widehat{m}_i - \widehat{c}_i + (1-\gamma)\widehat{a}_i + \zeta = 0$$

$$\psi = \beta_i[\psi - \frac{(1-\psi)}{\pi_{t+1}}]\gamma^{-\sigma} + \beta_i^2 \frac{1}{\pi}[r - r(1+\phi)\eta(\frac{\widehat{y_i}}{\kappa})^\phi + 1 - \psi]\gamma^{-2\sigma}$$

where $\widehat{y}_i = \widehat{w}e_i + r\widehat{a}_i$

Now substituting this back into the Euler equation we get :

$$\widehat{y}_i = \kappa[\frac{(r+1-\psi)\beta_i^2 + \gamma^2(\pi\psi - 1 + \psi)\beta_i - \psi\pi\gamma^{2\sigma}}{\beta_i^2 r\eta(1+\phi)}]^{\frac{1}{\phi}} = h(r, \beta_i) \qquad (A.17)$$

A.7 Calibration procedure

Using the functional forms and parameters discussed in the text, we fix β_{10}, to compute $\widehat{y}_{10}$ along a balanced growth path according to (A.17).

Since,

$$\widehat{y}_s = h(r, \beta_s)$$

Using data on $\{\widehat{y}_i\}_{i=1}^{10}$ we can compute: the following ratio:

$$\frac{\widehat{y}_i}{\widehat{y}_s} = \frac{h(r, \beta_i)}{h(r, \beta_s)} \tag{A.18}$$

This can be used to compute $\{\widehat{\beta}_i\}_{i=1}^{9}$. Then we can find the respective average incomes $\{\widehat{y}_i\}_{i=1}^{9}$ according to (A.17)

Also,

$$\widehat{w} = (1 - \alpha)(\frac{r^* + \delta}{\alpha})^{\frac{\alpha}{\alpha - 1}} \tag{A.19}$$

$$\widehat{y}_i = \widehat{w}(r)e_i + r\widehat{a}_i$$

$$\widehat{a}_i = \frac{\widehat{y}_i}{r^*} - \frac{\widehat{w}}{r^*}e_i = \frac{h(r, \beta_i)}{r^*} - \frac{\widehat{w}}{r^*}e_i$$

$$\sum_{i=1}^{s}\mu_i\widehat{a}_i = \sum_{i=1}^{s}\mu_i[\frac{h(r, \beta_i)}{r^*} - \frac{\widehat{w}}{r^*}e_i] = \widehat{K}^s(r) \tag{A.20}$$

The above equation tells us the supply of assets in the economy. We also normalize $\sum_{i=1}^{s}\mu_i e_i = 1$.

$$r^* = \alpha(\frac{K_t}{A_t L_t})^{\alpha-1} - \delta = aR - \delta \tag{A.21}$$

$$\frac{K_t}{A_t L_t} = (\frac{\alpha}{r^* + \delta})^{\frac{1}{1-\alpha}} = \widehat{K}^d(r) \tag{A.22}$$

The above equation tells us the demand for assets in the economy. In order to find the equilibrium interest rate, we find r* such that the supply of assets equals demand of assets in the economy, that is:

$$\widehat{K}^s(r) = \widehat{K}^d(r) \tag{A.23}$$

If $\widehat{K}^s(r) > \widehat{K}^d(r)$, we will decrease the rate of interest and if $\widehat{K}^s(r) < \widehat{K}^d(r)$, then we will increase the rate of interest, till supply equals demand.

Now eliminating $\widehat{c}_i$ from the following equations :

$$\widehat{m}_i - \widehat{c}_i - \psi(\gamma - 1)\widehat{a}_i = 0 \tag{A.24}$$

$$\widehat{y}_i - \widetilde{\tau}(\widehat{y}_i) + (1 - \pi\gamma)\widehat{m}_i - \widehat{c}_i + (1 - \gamma)\widehat{a}_i + \zeta = 0 \tag{A.25}$$

we get,

$$\widehat{m}_i - \psi(\gamma - 1)\widehat{a}_i = \widehat{y}_i - \widetilde{\tau}(\widehat{y}_i) + (1 - \pi\gamma)\widehat{m}_i + (1 - \gamma)\widehat{a}_i + \zeta \tag{A.26}$$

Aggregating the above equation and re-arranging we get,

$$\pi\gamma\sum_{i=1}^{s}\mu_i\widehat{m}_i + (\gamma - 1)(1 - \psi)\sum_{i=1}^{s}\mu_i\widehat{a}_i = \sum_{i=1}^{s}\mu_i(\widehat{y}_i - \widetilde{\tau}(\widehat{y}_i)) + \zeta \tag{A.27}$$

Substituting the following expression for transfers in the above equation:

$$\zeta = (g - 1)\sum_{i=1}^{s}\mu_i\widehat{m}_i \tag{A.28}$$

we get,

$$[\frac{\pi\gamma}{g - 1} - 1]\zeta = \sum_{i=1}^{s}\mu_i(\widehat{y}_i - \widetilde{\tau}(\widehat{y}_i)) - (\gamma - 1)(1 - \psi)\sum_{i=1}^{s}\mu_i\widehat{a}_i \tag{A.29}$$

Since $\pi\gamma = g$,

$$\widehat{\zeta} = (g - 1)[\sum_{i=1}^{s}\mu_i\widehat{y}_i\{1 - \eta(\frac{\widehat{y}_i}{\kappa})^\phi\} - (\gamma - 1)(1 - \psi)\sum_{i=1}^{s}\mu_i\widehat{a}_i \tag{A.30}$$

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Now, we define wealth of individual i as the sum of individual assets and money holdings, that is

$$\widehat{W}_i = \widehat{a}_i + \widehat{m}_i \tag{A.31}$$

$$\widehat{W}_i(r^*, \beta_i, e_i) = \frac{1}{g}[\widehat{y}_i\{1 - \eta(\frac{\widehat{y}_i}{\kappa})^\phi\} + \widehat{\zeta} + \underbrace{\{g - (\gamma - 1)(1 - \psi)\}}_{\chi}\widehat{a}_i] \tag{A.32}$$

$$\widehat{W}_i(r^*, \beta_i, e_i) = \frac{1}{g}[\underbrace{\widehat{y}_i\{1 - \eta(\frac{\widehat{y}_i}{\kappa})^\phi\} + \widehat{\zeta} + \frac{\chi}{r^*}\widehat{y}_i}_{\Omega_i} - \chi\frac{\widehat{w}}{r^*}e_i] \tag{A.33}$$

Now let us define:

$$\rho_i = \frac{\widehat{W}_i(r^*, \beta_i, e_i)}{\widehat{W}_1(r^*, \beta_1, e_1)} = \frac{\Omega_i - \chi\frac{\widehat{w}}{r^*}e_i}{\Omega_1 - \chi\frac{\widehat{w}}{r^*}e_1} \tag{A.34}$$

The above ratio can be computed from the data on wealth of the ten income groups from in the 2007 Survey of Consumer Finances (SCF) sample Díaz-Giménez et al. (2011). We can find e_1 by aggregating the above equation. Similarly, we can find labor productivity using the same equation for $\{e_i\}_{i=2}^{i=s}$

Chapter 2

Financial Instability and Monetary Policy

2.1 Introduction

The two main traditional goals of the U.S. Federal Reserve are to ensure maximum sustainable employment and price stability. The Great Moderation period since mid 1980s was characterized by low and stable inflation and relatively mild recessions, which was widely regarded as either a period of good policy or good luck. A closer look at the Great moderation period also reveals that financial markets have not experienced increased stability. The U.S. stock market had suffered several setbacks and crises as in the October 1987 crash, the 1997 Asian financial crisis, the 1998 Russian financial crisis, the consequent liquidation of the Long Term Capital Management L.P. (LTCM) hedge fund, the burst of the dotcom bubble of 2000 and most recently, the burst of the subprime mortgage bubble followed by the global financial meltdown. While the U.S. economy weathered most of these shocks with little impact on the real economy, it fell into its worst recession since the Great

Depression due to the global financial crisis. This recent experience has shown that even in the midst of low and stable inflation, major asset price misalignments can lead to a severe recession[1].

The intensity and scope of the subprime financial crisis along with the more recent sovereign debt crisis has revived the debate on whether and how central bankers should respond to financial instability. There is an increased interest in exploring the nexus between the role of monetary policy in dampening large asset price misalignments and minimizing or avoiding feedback loops to the real economic activity.

This paper attempts to address three questions: First, has the Federal Reserve responded to asset price fluctuations in the last 50 years? Second, if yes, has the Fed's reaction to stock market fluctuations changed between the Great Inflation and the Great moderation periods? Our third question captures the essence of the investigation in this paper. We implement a counterfactual scenario asking if the Federal Reserve had reacted to stock price misalignments in the Great moderation period, what would have been the implications of this policy on interest rates, output gap, stock prices and inflation. In other words, our paper attempts to analyze the nominal and real implications of a monetary policy rule that suggests that interest rates are set not only in response to inflation and output gap, but also in response to stock price misalignments. To our knowledge, this is the first paper that attempts to carry out such a counterfactual exercise for monetary policy analysis, particularly including the period of the recent financial crisis.

The debate on whether central banks should target asset prices is still incipient and economists have taken a polarized stance. On one hand, Bernanke and Gertler (2000),

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[1]Borio and Lowe (2002) claim that financial imbalances can build up in low-inflation environments, which is generally regarded as favorable to financial stability. They argue that the side effect of low inflation is that excess demand pressures may first appear in credit aggregates and asset prices than in consumer prices, which are normally considered by policy makers.

Bernanke and Gertler (2001) have addressed the efficacy of the central bank response to asset prices based on the financial accelerator framework presented in Bernanke et al. (1999a). In their framework, a shock to stock prices raises aggregate demand and drives up the price level. They suggest that by responding to inflation a central bank is already responding to asset price movements. In a recent study, Faia and Monacelli (2007) have supported their stance by suggesting that when monetary policy responds strongly to inflation, the marginal welfare gain of responding to asset prices vanishes. Gilchrist and Leahy (2002) and Carlstrom and Fuerst (2007), also find that the central bank does not have to target movements in asset prices because monetary policy rules that react strongly to inflation already incorporate the stabilization of asset prices. Posen (2006) has provided support for why central banks should not burst asset bubbles from a policy perspective. However, these conclusions have been challenged by Cecchetti et al. (2000) and Cecchetti et al. (2002) who argue that at least in inflation targeting countries, central banks should respond to asset prices. Using the same framework as in Bernanke and Gertler (2000), they show how a central bank can achieve increased stability by adjusting its policy instruments not only to inflation and output gap, but to asset price misalignments as well. In fact, Cecchetti et al. (2002) have made a distinction between targeting asset prices versus reacting to asset price misalignments, suggesting that it is the latter that enhances overall macroeconomic stability. The intuition behind their result is that asset price bubbles create distortions in investment and consumption, leading to excessive increases and then falls in both real output and inflation. Also, Kontonikas and Montagnoli (2006) show that asset price misalignments from their fundamentals should be included in the optimal interest rate reaction function. In another study by Ida (2011) shows, in an open economy framework, how reacting to both domestic asset prices and foreign asset prices can be welfare improving. Studies by Chadha

et al. (2004) and Haugh (2008) have also argued in favor of the central banks reaction to asset price misalignments[2]. In fact, Bordo and Jeanne (2002) have pointed out that the trade-off between current and future macroeconomic objectives is not exactly the same in an asset price boom as in normal times: it is between the cost of deviating from short-run macroeconomic objectives and the risk of severe economic dislocation in the future.

These papers however, study the implications of monetary policy in the presence of stochastic bubbles that can exist for a few periods before breaking, or assuming that asset price misalignments can arise due to fundamental or non fundamental factors. In actual asset markets however, asset price bubbles could be very difficult to identify and distinguishing a misalignment due to fundamentals or non fundamentals close to impossible.

In our paper, we take a more agnostic view of the sources of misalignments and focus on misalignments themselves. Our paper suggests a more systematic response to stock price misalignments. We analyse monetary policy within a framework where the central bank changes interest rates when asset price deviate from their long-run trend. This interest rate setting is important because we are analysing the implications of the monetary authority reacting to stock-price misalignments and not stock prices *per se*. Our motivation for analysing monetary policy within this setting lies in exploring if this framework would have offset the impact of asset price misalignments on output and inflation. Thus, in the light of recent debates on what should be the stance of monetary policy in the face of major asset price misalignments, our paper makes an important contribution.

The relationship between asset prices and the real economy provides an important argument for why central bankers should view their goals and financial stability as complementary. Large swings in asset prices can carry huge costs for the real economy

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[2]Roubini (2006) has argued from a policy perspective, how it might be beneficial for the central bank to burst bubbles.

as experienced in the aftermath of the recent financial crisis. The literature has identified the transmission of asset price fluctuations to the real economy through various channels [3](wealth effect, Tobin's Q effect, balance sheet effect and expectations). When asset prices rise, consumers increase their consumption as wealth rises, and businesses increase investment as the cost of capital falls. In addition, this increase in aggregate demand could lead to an upward pressure on inflation. On the other hand, during a major fall in asset prices cause significant contractions in real activity. Thus, it is through these mechanisms that asset price misalignments could endanger the achievement of the goals of the central bank.

Historically, it has been seen that the burst of asset price bubbles can cause real contractions in economic activity and long periods of deflation. For instance, the Japanese experience with the burst of the equity and real estate bubble of the 1980's has demonstrated how the lack of action by the Bank of Japan resulted in the "lost decade", characterizing poor and stagnating economic performance. This suggests that asset price misalignments cannot be ignored while deciding the stance of monetary policy.

In order to answer the questions addressed in this paper, we extend the standard New Keynesian model[4] to include asset prices. The first extension is carried out by assuming that firms in the monopolistic sector issue equity shares to households. The households can allocate their savings by buying either a riskless bond or risky stocks. This assumption is the same as suggested by the asset pricing model in Lucas (1978). This extension allows for our proposed New Keynesian model to have an equation that includes stock price dynamics. The second extension is carried out by assuming that stock prices affect aggregate demand. This implies that asset prices play a nontrivial role in determining output and thus inflation[5].

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[3]These channels are explored briefly in the next section.

[4]The standard New Keynesian models have become the workhorse of monetary policy analysis since they help us understand the relationship between monetary policy, inflation and the business cycle, see Woodford (2003).

[5]Filardo (2001) suggests a way to incorporate the effect of asset prices on aggregate demand. We use a

We then model the response of the central bank to stock market fluctuations by allowing the policy rate to be set in response to inflation, output gap, and stock price misalignments.

In this setting, our model presents several interesting features. First, with an equation explicitly driving stock price dynamics and a monetary policy rule reacting to stock price misalignments, we allow for a two-way interaction of monetary policy and stock prices: monetary policy decisions are affected by the stock market, and the stock market can be affected by monetary policy. Second, by letting stock prices affect aggregate demand, our model allows for stock prices to exert real effects on the economy. Our motivation to introduce stock prices into the interest rate setting stems from the fact that it has been argued that the central bank could potentially prevent the damages to economic activity caused due to an asset price bust by letting monetary policy react to asset price misalignments in the first place.

We estimate our New Keynesian model with asset prices using Bayesian techniques and by employing U.S. data. We find that the Federal Reserve did not react to stock price misalignments in the Great moderation period. By presenting a counterfactual policy experiment in which we let interest rates be set in response to inflation, output gap and stock price misalignments and comparing it to a rule when the interest rates are set only in response to inflation and output gap (our benchmark), we find several interesting results. Our counterfactual interest rates would have been higher on average as compared to the benchmark case. In fact, our counterfactual interest rates would have risen in response to a rise in real stock prices above their long run trend and fallen when real stock prices are below their long run trend. This behavior of our counterfactual interest rates is suggestive of a hypothetical preemptive action by the Fed in order to dampen misalignments in stock

framework similar to theirs.

prices. Interestingly, under this counterfactual scenario, we find that the boom-bust cycle of stock prices would have been milder and average output would not have been lower. In fact, raising interest rates prior to the Great Recession would have implied that the loss in output during the Great Recession would have been lower. Also, inflation would have been lower on average. These results indicate that the severity of the Great Recession would have been lower had real stock price misalignments been a part of the policy decisions of the Federal Reserve. In the wake of the Great Recession, our paper contributes to the current debate on whether central banks should target asset prices.

The organization of the paper is as follows: Section 2.2 presents an overview of the related literature on asset prices and monetary policy; Section 2.3 presents the New Keynesian Model with asset prices; Section 2.4 gives the canonical representation of the model; Section 2.5 explains the estimation procedure; Section 2.6 analyses empirical results from our estimations and Section 2.7 presents the counterfactual analysis. Section 2.8 concludes. All derivations and graphs can be found in the Appendix B.

2.2 Links between Asset prices, the real economy and Monetary policy

To motivate our study further, in this section, we briefly review the (1) the relationship between asset prices and the real economy, (2) the strand of literature that deals with financial instability, asset prices and monetary policy and (3) a few studies that discuss the link between asset prices and inflation.

2.2.1 Channels by which asset prices affect the real economy

The literature explores four broad channels via which asset prices affect the real economy. These are namely, the wealth effect, the Tobin's Q effect, the financial accelerator and the expectations channel. These arguments favor the inclusion of asset prices in monetary policy decisions.

According to the logic of the budget constraint, declining stock prices have direct effects on consumer spending since lower stock prices lower financial wealth of stockholders. Thus, asset prices have a direct wealth effect on consumer spending. Ludvigson and Steindel (1998) and Parker (2001) have found that there are modest effects of stock market on household wealth. Poterba (2000) finds that a dollar increase in financial assets leads to a 3 cents increase in consumption. The Tobin's Q effect, Tobin (1969) suggests that changes in equity prices may impact business fixed investment. Tobin's Q is the ratio of the valuation of firms relative to the replacement cost of capital. As equity prices rise, investment may be more profitable and vice-versa. Also, the channel via the financial accelerator as discussed in Bernanke et al. (1999a) is important for investment. Through this channel the level of net worth of entrepreneurs may play an important role in propagating shocks to the economy. They argue that successful investment today leads to greater entrepreneurial net worth tomorrow, thereby reducing the cost of capital tomorrow and increasing investment. In this way shocks to returns today are propagated into future periods. Further, asset price effects may occur since via uncertainty and impact expectations and confidence in the economy. Consumers who don't own stocks could also be affected by falling stock prices. Due to loss of confidence their own income prospects are dimmer and this may cause them to become more cautious of current spending and encourage precautionary savings. For a thorough evaluation of the magnitude of asset price fluctuations on the economy, see Davis (2010).

2.2.2 Financial instability, Asset Prices and Monetary Policy

Another area of interdependence involves the link between asset prices and monetary policy decisions. Some studies have focused on understanding both, whether monetary policy responds to asset price fluctuations and how strongly are the latter affected by shocks. Examples include Rigobon and Sack (2003), Rigobon and Sack (2004), Chadha et al. (2004), Bernanke and Kuttner (2005), Siklos (2008), Fuhrer and Tootell (2008) and Bjørnland and Leitemo (2009). All these papers find a strong interdependence between interest rate setting and real stock prices. These studies have looked at the immediate (short-run) effects of a monetary policy shock on the stock market and find that following a surprise interest rate increase, stock prices decline significantly. Also, Rigobon and Sack (2003) have analyzed reverse causation and find that stock market movements have a significant impact on short-term interest rates, driving them in the same direction as changes in stock prices.

A few studies specifically focus on the relationship between monetary policy rules and financial stability. However there is no unanimous view of whether a monetary policy should include some measure of financial stability. These theoretical studies include different indicators of financial stability like housing prices, equity prices, credit growth, banking stress, credit spreads etc. (e.g. Akram et al. (2007), Akram and Eitrheim (2008), Cecchetti and Li (2008), Bauducco et al. (2008), Christiano et al. (2008), Teranishi (2012)). An empirical study by Baxa et al. (2011) has shown that the Fed has responded to high financial stress by decreasing policy rates. Detken and Smets (2004) have found that monetary policy was significantly loose during high-cost booms that were followed by crashes of investment and real-estate prices. A few empirical studies measure the response of monetary policy to broader measures of financial imbalances. For instance, Borio and Lowe (2004) find that the Fed has reacted to financial imbalances in an asymmetric way. They find that the Fed

lowered the federal funds rate disproportionately as financial imbalances disentangled, but did not tighten policy as financial imbalances built up[6].

Another strand of literature has focused on the interactions between stock market fluctuations and monetary policy using similar models. Castelnuovo and Nisticò (2010) have found evidence of a strong role of stock prices via a wealth effect on the real economy. They also find evidence of a modest response of the Fed to stock price fluctuations. Nisticò (2012) has analyzed the role of stock prices in determining monetary policy consistent with price stability. Airaudo et al. (2007) have explored the issue of targeting stock prices from a determinacy perspective, Challe and Giannitsarou (2011) have investigated qualitative and quantitative evidence on effects of monetary policy shocks on stock prices, and Milani (2008) has analyzed the interactions between monetary policy, stock prices and the real economy in a near rational expectations model.

2.2.3 Asset prices and Inflation

There are two related questions with respect how a central bank should respond to asset prices for price stability purposes. (1) Should asset prices be considered in the measure of the general price level? and (2) Do asset prices help in forecasting inflation? The first question is addressed by Alchian and Klein (1973). They believe that price indices that are used by the central banks for instance, the CPI or the GDP deflator are inadequate because they consider only the price of goods consumed today. According to them, an adequate index of the cost of living would also include changes in the prices of future goods.[7] Their methodology suggests that an asset price boom will necessarily increase the cost of living

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[6]A recent study by Belke and Klose (2010) has investigated the factors behind the interest rate decisions of the Fed during the recent crisis.

[7]For instance, if housing prices were to rise, but rents remain unchanged, they would argue that the purchasing power of money had decreased even though the price index would show no effects.

which seems to be an impractical conclusion. Goodhart (2001) has discussed on what should be the appropriate weight of asset prices in measuring inflation. Since, some asset prices, notably housing, are closely associated with the main trends in inflation, and via 'bubbles and busts' with output disturbances, they suggest giving house prices more importance relative to other unstable asset prices in the measurement of inflation.

Regarding the second issue, with asset prices being able to forecast inflation, there is little consensus. The proponents of broader measures of inflation favor the inclusion of asset prices[8] However, Stock and Watson (1999) find that asset prices perform very poorly in forecasting inflation for a one year horizon[9]

2.3 Model

The model comprises of households that supply labor, consume goods, hold risk-free bonds and risky assets, and firms that hire labor to produce and sell differentiated products in monopolistically competitive goods markets. Each firm sets the price of the good it produces, but only a fraction of firms can reset their prices in any given period. Households and firms behave optimally: households maximize the expected present value of utility whereas firms maximize profits. The part with households and firms constitutes the non monetary policy block of the model. The monetary policy block of the model consists of a central bank that sets the nominal rate of interest which is discussed in Section 2.4. Our model is inspired by Galí (2008), Walsh (2003), Nisticò (2012) and Filardo (2001).

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[8]This is because they predict future movements in the CPI. Also, Fisher (1911) argued that increases in the money supply were first manifested in rising asset prices and only later in the prices of consumer goods.

[9]Some studies have still made a case about why house prices should be included to predict inflation. Real estate booms appear to have preceded inflation in Japan and the United Kingdom in the 1980's. Goodhart and Hofmann (2000) find that housing prices enter significantly into forecasting inflation for 12 countries. However, Cecchetti et al. (2000) and Filardo (2000) report the inclusion of housing does not significantly improve the performance of inflation forecasts.

2.3.1 Households

We assume a representative infinitely-lived household, seeking to maximize

$$E_t \sum_{k=0}^{\infty} \beta^k U(C_{t+k}, N_{t+k}) \tag{2.1}$$

where $U(C_t, N_t)$ is the period utility function and consumers discount utility at the rate of $\beta < 1$.

We assume the existence of a continuum of goods[10] represented by the interval $[0, 1]$. The household decides how to allocate its consumption expenditures on the different goods. This requires that the consumption index C_t be maximized for any given level of expenditures. Conditional on this optimal behavior of households[11], the budget constraint takes the form

$$P_t C_t + Q_t B_t + \widehat{P}_t^s S_t \leq B_{t-1} + W_t N_t - T_t + \widehat{P}_t^s S_{t-1} + P_t D_t S_{t-1} \tag{2.2}$$

for t=0,1,2..., where P_t is the aggregate price index[12], W_t is the nominal wage rate, received by supplying labor N_t. Households can invest in two types of financial assets: bonds and equity shares which are issued by monopolistically competitive firms, to which they also supply labor[13]. The quantity of one-period, nominally riskless discount bonds purchased in time period t is represented by B_t and they mature in the subsequent period, $t + 1$. Each bond pays one unit of money at maturity and its price is given by Q_t. The nominal interest rate is given by $i_t = -log(Q_t)$. The nominal lump-sum taxes are represented by

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[10]The consumption index is given by $C_t \equiv \left(\int_0^1 C_t(i)^{1-\frac{1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}}$ where $\varepsilon > 1$ is the elasticity of substitution among differentiated goods.

[11]To see how this optimal behavior given by $\int_0^1 P_t(i) C_t(i) di = P_t C_t$ is derived, refer to Appendix B

[12]The aggregate price index is given by $P_t \equiv \left[\int_0^1 P_t(i)^{1-\varepsilon} di \right]^{\frac{1}{1-\varepsilon}}$

[13]We assume a cashless economy following Woodford (2003)

T_t. The nominal price of the quantity of the risky financial asset S_t is given by $\widehat{P}_t^s = P_t P_t^s$ where P_t^s is the real price (in terms of the market basket of consumption goods given by the consumption index C_t) of the financial asset. The real dividends denoted by D_t are paid at time t to holders of the asset at $t-1$. The above sequence of period budget constraints is supplemented with a solvency condition, such as $\forall t \; lim_{T\to\infty} \beta^T(B_T + P_T(P_T^s S_T + D_T)) \geq 0$ that implies that the household does not engage in Ponzi schemes. The regular assumptions apply to the utility function[14]

Under the assumption of period utility given by

$$U(C_t, N_t) = \frac{C_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\phi}}{1+\phi} \tag{2.3}$$

consumption, labor, bond and financial asset holdings are chosen to maximize (2.1) subject to (2.2) and the solvency condition. The parameter σ is the coefficient of relative risk aversion of households (also, the inverse of the intertemporal elasticity of substitution) and ϕ is the inverse of the elasticity of work effort with respect to the real wage. The intra and inter-temporal optimality conditions are given by

$$\frac{W_t}{P_t} = C_t^\sigma N_t^\phi \tag{2.4}$$

$$Q_t = \beta E_t\left\{\left(\frac{C_{t+1}}{C_t}\right)^{-\sigma}\frac{P_t}{P_{t+1}}\right\} \tag{2.5}$$

$$P_t P_t^s = E_t[Q_t P_{t+1}(P_{t+1}^s + D_{t+1})] \tag{2.6}$$

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[14]The expected value of utility where the period utility function is given by $U(C_t, N_t)$ is assumed to be twice continuously differentiable, with $U_{c,t} > 0$, $U_{cc,t} \leq 0$, $U_{cc,t} \leq 0$, $U_{n,t} \leq 0$ and $U_{nn,t} \leq 0$. This implies that the marginal utility of consumption, given by $U_{c,t}$, is positive and nonincreasing and the marginal disutility from working (labor), given by $-U_{n,t}$, is positive and nondecreasing.

Equation (2.4) gives the intra temporal optimality condition that governs the trade-off between consumption and leisure and can be interpreted as the labor supply schedule, determining the quantity of labor supplied as a function of the real wage, given the marginal utility of consumption. Equation (2.5) yields the familiar euler equation and requires that in equilibrium, the marginal utility of consumption inter-temporally equalizes through the adjustment of the real interest rate. Equation (2.6) defines the nominal price of total equity shares as the discounted value of the future expected payoffs.

2.3.2 Firms

We assume a continuum of monopolistically competitive firms indexed by $i \in [0,1]$ which produce a continuum of differentiated goods using identical technology, represented by the production function

$$Y_t(i) = A_t N_t(i)^{1-\alpha} \tag{2.7}$$

where A_t represents the level of technology, assumed to be common to all firms and to evolve exogenously over time and $N_t(i)$ represents labor. Firms face identical demand schedules[15] given by $Y_t(i) = (\frac{P_t(i)}{P_t})^{-\varepsilon} Y_t$ where aggregate output is given by $Y_t \equiv \left(\int_0^1 Y_t(i)^{1-\frac{1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}}$ and take the aggregate price level P_t and aggregate consumption index C_t as given. Price setting is introduced in a staggered fashion following Calvo (1983); each firm may reset its price only with probability $1 - \theta$ in any given period, independent of the time elapsed since the last adjustment. Thus, each period a measure $1 - \theta$ of producers reset their prices, while a fraction of θ keep their prices unchanged[16]. Thus, we can denote θ as the measure of natural index of price stickiness.

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[15]This results from the intratemporal decision of the households and from $C_t = Y_t$.
[16]This means that the average duration of a price is given by $(1 - \theta)^{-1}$

Each firm faces the same decision problem and, if allowed to re-optimize, sets the same price P_t^* to maximize the expected present discounted value of future profits. Basically, the firm reoptimizing in period t will choose the price P_t^* that maximizes the current market value of the profits generated while that price remains effective. Formally,

$$max \quad \sum_{k=0}^{\infty} \theta^k E_t(Q_{t,t+k}(P_t^* Y_{t+k|t} - \Psi_{t+k|t} Y_{t+k|t}))$$

subject to the sequence of demand constraints

$$Y_{t+k|t} = (\frac{P_t^*}{P_{t+k|t}})^{-\varepsilon} C_{t+k}$$

for k=0, 1, 2...

where $Q_{t,t+k} \equiv \beta^k (\frac{C_{t+k}}{C_t})^{-\sigma} \frac{P_t}{P_{t+k}}$ is the stochastic discount factor, $\Psi(\cdot)$ is the cost function and $Y_{t+k|t}$ denotes output in period t+k for a firm that last reset its price in time t. The appendix further describes the optimal price setting of firms.

2.3.3 Equilibrium

Our model is characterized by four markets: the bonds market, the equity market, the goods market and the labor market. The equilibrium in these four markets is given as follows:

In the bonds market, the net supply of bonds is equal to zero, i.e.

$$B_t = 0$$

In the equity market, the total amount of issued shares by the firms is normalized to one,

$$\int S_t(i) = 1$$

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Also, the total real dividends and the aggregate stock price index are defined by aggregating over a continuum of firms as

$$D_t = \int_0^1 D_t(i)di$$

and

$$P_t^s = \int_0^1 P_t^s(i)di$$

On the aggregate demand side, we have market clearing conditions that hold in equilibrium along with the euler equations mentioned in the previous section. The market clearing in the goods market requires

$$Y_t(i) = C_t(i)$$

$\forall i \in [0,1]$ and all t. Aggregate output is defined as $Y_t \equiv \left(\int_0^1 Y_t(i)^{1-\frac{1}{\varepsilon}}di \right)^{\frac{\varepsilon}{\varepsilon-1}}$ and thus it follows that

$$C_t = Y_t$$

must hold $\forall t$ and

$$P_t Y_t = W_t N_t + P_t D_t$$

Also, the labor market clearing condition requires,

$$N_t = \int_0^1 N_t(i)di$$

2.4 The Canonical Representation

We can write out the reduced form of our New Keynesian model with asset prices using equations that are log-linearized around a zero inflation steady state. We can characterize the model by two blocks: (1) the non monetary policy block that represents the demand side, supply side and stock price dynamics and (2) the monetary policy block that represents a monetary policy rule with the help of which we close the model. The derivation of these equations have been described in the Appendix B.

2.4.1 Non monetary policy block

The Dynamic IS curve:

$$\widetilde{y}_t = E_t\widetilde{y}_{t+1} - \frac{1}{\sigma}(i_t - E_t\pi_{t+1} - r_t^n) + \zeta s_t \tag{2.8}$$

where $\widetilde{y}_t$ denotes output gap, π_t is the inflation rate, i_t is the policy rate set by the central bank and s_t is the real stock price gap.

The evolution of the natural rate of interest, r_t^n is given by:

$$r_t^n = \rho + \sigma E_t \Delta a_{t+1} \tag{2.9}$$

We assume that technology, a_t follows an AR(1) process with persistence ρ_a

$$a_t = \rho_a a_{t-1} + \varepsilon_a \tag{2.10}$$

Equation (2.8) represents the log-linearized intertemporal Euler equation that is derived from the households' choice of consumption. The standard IS curve is now augmented to allow for the inclusion of a channel through which there is a direct effect of

stock price fluctuations on output gap. The magnitude of this feedback effect is given by ζ. This equation suggests that the output gap can be determined given the path for the exogenous natural rate r_t^n and the actual real rate given by $r_t = i_t - E_t\pi_{t+1}$. It also depends on the one-period ahead output gap and current real-stock price gap. Here we have used the specification analogous to the one used in Filardo (2001) for the feedback effect from stock prices to output[17]. The difference is that he has suggested a similar representation in terms of growth rates of stock prices affecting growth rate of output. Our representation is in terms of real stock price gap affecting output gap. The essence is however the same and captures the conventional wisdom that increases in asset prices boost aggregate demand.

The New Keynesian Phillips Curve:

$$\pi_t = \beta E_t\pi_{t+1} + \kappa\widetilde{y_t} + b_t \tag{2.11}$$

We assume that the cost-push, b_t shock follows an AR(1) process with persistence ρ_b

$$b_t = \rho_b b_{t-1} + \varepsilon_b \tag{2.12}$$

Equation (2.11) is the forward looking New-Keynesian Phillips curve. Inflation depends on expected inflation in $t+1$ and on current output gap. The slope of the Phillips curve is given by κ which is inversely related to price stickiness, θ.

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[17]He has suggested that augmenting the IS curve this way allows for asset prices to affect output in different ways. For instance, as discussed earlier, an increase in asset prices would increase consumption via a wealth effect or increase investment by lowering the cost of capital etc.

Stock-price dynamics:

$$s_t = \beta s_{t+1} + \gamma E_t \widetilde{y}_{t+1} - \frac{1}{\sigma}(i_t - E_t \pi_{t+1} - r_t^n) + e_t \tag{2.13}$$

We assume that the stock-price shock, e_t follows an AR(1) process with persistence ρ_e

$$e_t = \rho_e e_{t-1} + \varepsilon_e \tag{2.14}$$

Equation (2.13) drives stock price dynamics. Stock prices are forward looking because the real stock price gap, s_t depends on its own one-period ahead expectations and on expectations about future output gap and on the exogenous natural rate r_t^n and the actual real rate given by $r_t = i_t - E_t \pi_{t+1}$.

Equations (2.8) and (2.11) together with an equilibrium process for the natural rate and stock price dynamics constitute the non-policy block of our New-Keynesian model. The next subsection describes monetary policy.

2.4.2 Monetary Policy block

Benchmark Taylor rule:

The central bank is assumed to set its nominal interest rate according to a Taylor rule, Taylor (1993). This rule suggests that interest rates are set in response to changes in inflation and output gap.

$$i_t = \rho + \phi_\pi \pi_t + \phi_y \widetilde{y}_t + \upsilon_t \tag{2.15}$$

The parameters ϕ_π and ϕ_y are coefficients on inflation and output gap respectively. The monetary policy shock is given by υ_t.

We assume that monetary policy follows an AR(1) process with persistence ρ_v:

$$v_t = \rho_v v_{t-1} + \varepsilon_v \tag{2.16}$$

Augmented Taylor rule:

In our second model we consider an augmented Taylor rule that suggests that the central bank sets the policy rate not just in response to changes in inflation and output gap but also in response to a deviation of the real stock prices from its trend[18]. The monetary policy shock is the same as in the benchmark case.

$$i_t = \rho + \phi_\pi \pi_t + \phi_y \widetilde{y}_t + \phi_s s_t + v_t \tag{2.17}$$

where the coefficient ϕ_s represents the weight on the deviation of real stock prices from its trend.

An advantage of using this framework for policy analysis is that even with a parsimonious structure of the economy, we are able to allow for interactions between the stock market, the real economy and monetary policy[19]. This structure of the model economy can be seen as complementing medium scale models like Bernanke and Gertler (2000).

2.5 Estimation

In this section, we describe the estimation procedure and data, the calibrated parameters and our prior distribution of parameters.

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[18]The flexible price or natural rate of output can be interpreted as the long run trend for our empirical exercise.

[19]Since we are linearizing the model, the equation with stock price dynamics may not best represent stock price dynamics. However, even a linearized characterization is useful for the purpose of this paper.

2.5.1 Estimation procedure and data

As in An and Schorfheide (2007), the model presented in the previous section is estimated with Bayesian techniques using four macroeconomic quarterly US time series as observable variables: the log of real GDP (detrended), the real stock price gap, log difference of CPI and the federal funds rate. We do not opt to estimate our model using maximum likelihood techniques because such computation hardly converges to a global maximum.

The vector Φ contains the parameters that will be estimated in our model:

$$\Phi = [\kappa, \gamma, \phi_\pi, \phi_y, \phi_s, \rho_a, \rho_b, \rho_e, \rho_v, \sigma_a, \sigma_b, \sigma_e, \sigma_v]$$

We use quarterly data starting from 1959Q1 to 2012Q2 on real GDP, the S&P 500 stock price index, the CPI and the federal funds rate. The output gap $\widetilde{y}_t$ is computed by taking the difference between the log of the real GDP from the potential real GDP. The real stock-price gap, s_t is computed by deflating the S&P 500 index by the CPI and then detrending it using the Hodrick-Prescott filter[20]. Inflation, π_t, is computed as the annualized quarterly change in CPI. The nominal interest rate denoted by i_t is taken directly as the federal funds rate in levels. The data is obtained from the FRED[21]. The important point to be noted here is that we use empirical definitions of output gap and real-stock price gap for our estimation. These do not correspond to the theoretical definitions of deviations of output gap and real stock price gap from their flexible price level. However, we want to focus on more data-driven results and thus use the empirical definitions. A plot of the real-stock price gap series and output gap series is presented in figure B.1. It suggests that the real stock price gap series is much more volatile than output gap. More interestingly, the real stock price gap falls prior to each recession. Table B.1 reports the standard deviations

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[20]The series are detrended using a smoothing parameter of 1600.
[21]Federal Reserve Economic Data (FRED)

of the real stock price gap series, output gap and inflation between 1959-2012 as well the

Great Inflation and Great Moderation periods. Even though the volatility of inflation and

output gap has fallen during the Great moderation period, the volatility of the real stock

price gap has increased substantially.

We also consider two sub-samples to see a shift if any in monetary policy[22].

The first sub-sample ranges from 1959Q1-1983Q4 and the second sub-sample ranges from

1984Q1-2012Q2. The model is estimated using Bayesian techniques to fit the output gap,

real stock price gap, inflation, and the federal funds series and the structural parameters

of our model. First, we estimate the mode of the posterior distribution by maximizing the

log posterior function, which combines the prior information on the parameters with the

likelihood of the data. Second, using the Metropolis-Hastings algorithm we generate draws

from the posterior distribution. At each iteration, the likelihood is evaluated using the

Kalman filter[23]. We consider 200,000 draws, discarding 20% as initial burn in. The scale

used for the jumping distribution is set to a value consistent with an acceptance rate in the

neighborhood of 25% to ensure that we identify also the tails of the distribution correctly.

2.5.2 Calibrated parameters

There are few parameters that are fixed prior to our estimation. The discount

factor β is fixed at 0.99. The choice of 0.99 corresponds to the long-run annual interest rate

of 4%. Also, the coefficient of relative risk aversion, σ is fixed to be one, corresponding to

log utility as assumed in Galí (2008). Also, we fix ζ, the parameter governing the effect

of stock prices on aggregate demand to be 0.2, following Castelnuovo (2012) and Filardo

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[22]Some authors have found evidence in favor of a monetary policy shift at the beginning of 1980's, see
Clarida et al. (2000), Boivin and Giannoni (2006).

[23]All estimations are done using Dynare. For more information on its implementation and usage, see
Adjemian et al. (2011).

(2001).

2.5.3 Prior distribution of parameters

Following standard conventions, we calibrate beta distributions for parameters that fall between zero and one, inverted gamma distributions for parameters that need to be constrained greater than zero and normal distributions in other cases.

These priors are similar to the ones specified by Smets and Wouters (2007). The standard errors of the innovations are assumed to follow an inverse-gamma distribution with a mean of 0.02 and two degrees of freedom. The latter ensures that that these parameters have positive support. The persistence of the AR(1) processes are assumed to follow a beta distribution with mean 0.5 and standard deviation 0.1 as in Smets and Wouters (2003) except for the technology shock that is assumed to have a mean of 0.9.

The parameters that describe monetary policy are based on the standard Taylor rule. We assume that the reaction of the nominal interest rate to inflation and output gap is described by a normal distribution with mean 1.5 and 0.125 (0.5/4) as described by Galí (2008). The reaction of the nominal interest rate to the real stock-price gap is also assumed to follow a normal distribution with mean close to zero and a standard deviation of 0.25. This parameter is of particular interest in our study because it determines the systematic response of monetary policy to the fluctuations to the stock price gap. For all parameters in the Taylor rule, we let the data determine as much as possible of the sign and magnitude of the responses by assuming a normal distribution. The prior of 0.5 for κ was associated with a a value of the price stickiness parameter, $\theta = 3/4$ as specified in Galí (2008).

2.6 Empirical Results

Parameter	Decription	Prior			Posterior		
		Law	Mean	SD	Mean	5 percent	95 percent
κ	Slope of PC	Beta	0.5	0.05	0.6845	0.6400	0.729
γ	SP resp. to o/p	Normal	0	0.05	0.2495	0.0	0.499
ϕ_π	Fed's resp. to inf.	Normal	1.5	0.05	1.5934	1.5303	1.6398
ϕ_y	Fed's resp. to o/p gap	Normal	0.125	0.25	0.3151	0.2027	0.4276
ρ_a	AR coeff, tech.	Beta	0.9	0.1	0.9750	0.9580	0.9930
ρ_b	AR coeff, cost push	Beta	0.5	0.1	0.9396	0.9255	0.9529
ρ_e	AR coeff.,SP	Beta	0.5	0.1	0.9010	0.8425	0.9595
ρ_v	AR coeff, MP	Beta	0.5	0.1	0.5078	0.4738	0.5504
σ_a	SE, tech. shock	InvGamma	0.02	2	0.0041	0.0036	0.0046
σ_b	SE, cost push shock	InvGamma	0.02	2	0.0087	0.0047	0.0096
σ_e	SE, SP shock	InvGamma	0.02	2	2.9674	1.5345	4.4003
σ_v	SE, MP shock	InvGamma	0.02	2	0.0187	0.0171	0.0204
Log marginal likelihood = 1084.68							

Table 2.1: Estimation results for model (Benchmark): Full sample, 1959-2012

Table 2.1 presents the posterior estimates for our benchmark model as summarized by the canonical representation of the model between 1959 and 2012. It presents the posterior mean and the 5% and 95% confidence percentiles of the posterior distribution of the parameters obtained by the Metropolis-Hastings algorithm. For the benchmark model we assume that the Federal Reserve only responds to inflation and output gap. Parameters ϕ_π and ϕ_y determine the reaction of the Federal Reserve to inflation and output gap. We find that our model estimates a significant response of the Fed to inflation and output gap. The posterior mean of ϕ_π is about 1.59 with a Bayesian posterior interval of [1.53, 1.63] and the posterior mean of ϕ_y is about 0.31 with a Bayesian posterior interval of [0.2, 0.42]. The estimate of the reaction of the Fed to inflation is pretty close to the value estimated by Smets and Wouters (2007) and also suggests that the reaction of the Fed to inflation followed the Taylor principle. The Taylor principle is the proposition that central banks can stabilize the macroeconomy by raising their interest rate instrument more than one-for-one

in response to higher inflation[24]. However, the response of policy to output gap seems to be strong in our model as compared to the estimates of Smets and Wouters (2007). This is probably because in the reaction function of the central bank they include two responses to output. The first being the response to output gap and the second being the response to the changes in output gap. However, they do find a strong response of policy to the changes in output gap. Since, we don't allow for such a specification for the monetary policy rule, our estimate of ϕ_y could probably be capturing both, the response of output gap and changes in output gap.

The slope of the Phillips curve is given by κ and we find that the estimated value of 0.68 suggests a moderately steep curve. We find that the parameter γ, that governs the response of the real stock price gap to expectations about future output gap is highly significant. A number of observations can be made with respect to our estimated responses for the exogenous shock variables. Overall, the data are very informative regarding the stochastic processes for these exogenous disturbances. The technology, cost-push, stock price shock are highly persistent with an AR(1) coefficient of 0.97, 0.93 and 0.9 respectively. However, the persistence of the monetary policy shock is much lower at around 0.5. In terms of the standard deviations, we find that the technology, cost-push and monetary policy shock have a low standard deviation. The standard deviation of the the stock price shock is high because the error term in the equation governing stock price dynamics can account for fluctuations in asset prices that are not linked to fundamentals, for instance, it could account for bubbles, irrational exuberance etc.

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[24]In the model, this suggests that the response of the Federal reserve to inflation given by $\phi_\pi > 1$.

Parameter	Description	Prior			Posterior		
		Law	Mean	SD	Mean	5 percent	95 percent
κ	Slope of PC	Beta	0.5	0.05	0.61	0.5078	0.7122
γ	SP resp. to o/p	Normal	0	0.05	0.2163	0.0	0.4326
ϕ_π	Fed's resp. to Inf.	Normal	1.5	0.05	1.4506	0.4083	2.3358
ϕ_y	Fed's resp. to o/p gap	Normal	0.125	0.25	0.2043	0.1124	0.2962
ϕ_s	Fed's resp. to SP gap	Normal	0.05	0.25	0.2163	0.1167	0.3159
ρ_a	AR coeff.,Tech	Beta	0.9	0.1	0.9512	0.8811	1.000
ρ_b	AR coeff.,CP	Beta	0.5	0.1	0.9392	0.8850	0.9750
ρ_e	AR coeff.,SP	Beta	0.5	0.1	0.9025	0.8504	0.9663
ρ_v	AR coeff.,MP	Beta	0.5	0.1	0.5426	0.4092	0.676
σ_a	SE, Tech shock	InvGamma	0.02	2	0.0087	0.0079	0.0096
σ_b	SE, CP shock	InvGamma	0.02	2	0.0905	0.0317	0.1577
σ_e	SE, SP shock	InvGamma	0.02	2	2.9824	1.5529	4.6949
σ_v	SE, MP shock	InvGamma	0.02	2	0.0081	0.0063	0.0099
Log marginal likelihood = 1119.87							

Table 2.2: Estimation results for model with stock market: Full sample, 1959-2012

Table 2.2 presents the posterior estimates for our second model that assumes that now policy reacts to inflation, output gap as well as stock price gap between 1959 to 2012. We can evaluate the importance of including the stock-price gap in the Taylor rule by comparing the log-marginal likelihood of this model to the benchmark case. We find that including the stock price gap in the Taylor rule raises the log- marginal likelihood by about 35 points indicating that the data support the fact that the Fed had reacted to stock price fluctuations over the entire period we consider. In fact, if we compare the responses of the Fed to inflation and output gap between the two models considered, we come across an interesting finding. Excluding the stock price gap in the Taylor rule leads to an increase in the weights of the response of the Fed to inflation and output gap, suggesting that the reaction to inflation and output gap in the Taylor rule is replacing the response to the stock price gap. This can be further explained by our model. In our model, stock prices exert real effects on output directly via the augmented IS curve and indirectly on inflation via the Phillips curve. This further justifies the importance of the presence of the stock price

gap in the Taylor rule.

Comparing the two tables, we can say that the data suggest a significant and systematic response of monetary policy of the Federal Reserve to stock market fluctuations. However, this systematic response can be understood in two ways. First, by assuming that the Fed responds to the stock market fluctuations as it is. However, the second interpretation of this reaction to stock market fluctuations could be that the Fed is reacting to the stock market only to the extent that it carries information regarding future inflation and output gap. This view has been explored by Fuhrer and Tootell (2008) who show that the Fed reacted to stock market fluctuations with the Taylor rule in a similar setting. They also control for real-time forecasts in their analysis to see if the Fed actually reacted to stock market fluctuations or the reaction was only to the extent that the stock market was a good predictor of inflation and output gap. Their finding supports the latter view. Following them, we also allow for different specifications of the Taylor rule to respond to forward looking variables like inflation and output but still allowing for a contemporaneous response to the stock price gap. With this exercise, we do find that the weight on the reaction to stock price gap falls and lies in the range [0.14, 0.17] but still remains significant. Our finding is at odds with Fuhrer and Tootell (2008) probably because they use real-time forecasts and in our model forward looking variables capture actual inflation and output gap in future periods.

In our next exercise, we consider two sub-samples. The first sub-sample is the Great Inflation period from 1959 to 1983 and the second sub-sample is the Great Moderation period from 1984-2012. We treat this break at 1983 as exogenous because several authors have documented the reduction of variability of inflation and output in the United States

since the beginning of the 1980s[25]. Our estimates for these sub-samples are reported in Table 2.3 and Table 2.4 respectively. First, considering the Great Inflation period, we find that the response of the Fed to inflation has been very strong with the response coefficient $\phi_\pi = 1.52$. Also, the response coefficients for output gap and real stock price gap are highly significant taking values $\phi_y = 0.23$ and $\phi_s = 0.17$, respectively. Comparing these results to the Great Moderation period, we find that even though the response coefficients of inflation and output gap are strong, with $\phi_\pi = 1.54$ and $\phi_y = 0.25$, the response of the Fed to the real stock price gap is close to zero, $\phi_s = 0.05$. In fact, when we repeated the estimation exercise using different specifications of the Taylor rule with forward looking variables of inflation and output gap, the response coefficient to real stock price gap becomes zero and sometimes takes a small negative value. This suggests that the Fed did not react to stock market fluctuations during the Great moderation period.

Parameter	Prior			Posterior		
	Law	Mean	SD	Mean	5 %	95 %
κ	Beta	0.5	0.05	0.6172	0.5268	0.6973
γ	Normal	0	0.05	0.1367	0.0437	0.2297
ϕ_π	Normal	1.5	0.05	1.5228	1.4626	1.6174
ϕ_y	Normal	0.125	0.25	0.2392	-0.144	0.5846
ϕ_s	Normal	0.05	0.25	0.1725	0.1217	0.2233
ρ_a	Beta	0.9	0.1	0.9489	0.9097	0.9928
ρ_b	Beta	0.5	0.1	0.8235	0.7834	0.8636
ρ_e	Beta	0.5	0.1	0.8562	0.8024	0.9245
ρ_v	Beta	0.5	0.1	0.503	0.4104	0.5712
σ_a	InvGamma	0.02	2	0.0065	0.0044	0.0085
σ_b	InvGamma	0.02	2	0.0101	0.0084	0.0118
σ_e	InvGamma	0.02	2	3.20	3.0564	3.3436
σ_v	InvGamma	0.02	2	0.0234	0.0202	0.0267
Log marginal likelihood = 576.99						

Table 2.3: Estimation results for model with stock market: 1959-1983

[25]See, for example, McConnell and Perez-Quiros (2000) and Blanchard and Simon (2001)

	Prior			Posterior		
Parameter	Law	Mean	SD	Mean	5 %	95 %
κ	Beta	0.5	0.05	0.6144	0.5472	0.6901
γ	Normal	0	0.05	0.1245	0.0465	0.2025
ϕ_π	Normal	1.5	0.05	1.5448	1.4875	1.5978
ϕ_y	Normal	0.125	0.25	0.2503	-0.1077	0.735
ϕ_s	Normal	0.05	0.25	0.052	-0.002	0.106
ρ_a	Beta	0.9	0.1	0.9469	0.8906	0.9946
ρ_b	Beta	0.5	0.1	0.8549	0.7718	0.9144
ρ_e	Beta	0.5	0.1	0.8562	0.8024	0.9245
ρ_v	Beta	0.5	0.1	0.5217	0.4306	0.6218
σ_a	InvGamma	0.02	2	0.0066	0.0044	0.0093
σ_b	InvGamma	0.02	2	0.0101	0.0084	0.0118
σ_e	InvGamma	0.02	2	3.24	3.0345	3.4455
σ_v	InvGamma	0.02	2	0.0239	0.0206	0.0268
Log marginal likelihood = 576.92						

Table 2.4: Estimation results for model with stock market: 1984-2012

2.7   Counterfactual Taylor rule with stock prices

In this section, we present a description of our counterfactual exercise followed by an analysis of our results. We then provide some intuitions behind how our model justifies the results we obtain.

By counterfactual we mean "what would have occurred if some observed characteristic or aspect of the policy rule under consideration was different prevailing at the time". This exercise can be thought of as reflecting a "what if" scenario. In effect, we are interested in comaparing an ex post realized outcome with a counterfactual outcome that could have been obtained under an assumption about the policy rule[26].

We focus on two alternative approaches to monetary policy. The first is the traditional operational Taylor rule approach that only targets inflation and output gap. The second rule is the augmented Taylor rule that along with inflation and output gap targets

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[26]One such example can be found in Orphanides and Williams (2012) where their counterfactual experiment suggests that under a different policy rule, the Great Inflation could have been avoided

stock price gap. In both cases, the policy instrument is the nominal short-term interest rate. We assume that the central bank observes all variables from the current period when making the current-period policy decision. We examine a counterfactual scenario for each variable in our model: interest rates, inflation, output gap and real stock price gap, to investigate the implications of a Taylor rule augmented stock price gap on macroeconomic developments in the period after 1984. Our simulations start in the first quarter of 1984, which corresponds to the beginning of the Great moderation in the United States.

In order to perform this experiment, we assume that all our non monetary policy parameters remain the same and monetary policy is set according to the parameters obtained from the first sub-sample when the response of the Federal Reserve to stock market fluctuations is around $\phi_s \approx 0.2$. In our analysis, we want to compare the outcome of following this counterfactual interest rate rule with the one actually obtained in the post 1984 sub-sample when $\phi_s = 0$. We are interested in this particular time period because stock market volatility has been higher in this sample period as compared to the first sub-sample.

We present our results in two ways. First, we compare graphically, the outcome of following the counterfactual Taylor rule that suggests that policy is set in response to stock price misalignments in addition to output gap and inflation to the outcome obtained by following the standard Taylor rule that suggests that policy is set only in response to inflation and output gap. Second, we present a comparison of the mean and variance of each of the series obtained in this counterfactual exercise.

In our graphical comparison, we present each of our series i.e. interest rates, inflation, output gap and stock price gap in Figures B.2,B.3,B.4 and B.5 respectively. For interest rates, the graph suggests that if the Fed reacted to stock price misalignments, interest rates would have been higher on average (the blue line in figure B.2) as compared

to the traditional Taylor rule (the red line). In fact, the counterfactual interest rates show a very interesting pattern. It can be seen how the counterfactual interest rates rise in response to a major misalignment in stock prices on three different occasions. First, prior to the 1987 stock market crash, the counterfactual interest rate would have suggested that the Fed should have raised interest rates in response to rising stock prices, as marked in the figure. Consequently, with falling stock prices, the interest rate rule would suggest that interest rates be lowered in response to falling stock prices to stimulate the economy. Second, prior to the dotcom bubble of 2000 and at the time when the stock market exhibited irrational exuberance, the counterfactual interest rate rule would have suggested that interest rates should have risen prior to 2000. This can be thought of as the Fed trying to take a preemptive action to put a downward pressure on stock prices. Subsequently, after the stock market crash, the interest rates be lowered in response to falling stock prices. Finally, we find that our counterfactual interest rate rule would have suggested that interest rates would have risen in response to the boom in stock prices associated with the housing market in the mid 2000s followed by a sharp decline following the decline in stock prices. Thus, in many aspects, our counterfactual interest rate captures the dynamics of our real-stock price gap series.

Next, we can compare what would the path of inflation be under the two scenarios as given in figure B.3. Plain eyeballing reveals that inflation would have been lower under the counterfactual scenario. This result is in line with our conventional wisdom suggesting that higher interest rates put a downward pressure on inflation. In terms of output gap as given by figure B.4, we find that even with higher interest rates, no major recession would have been caused between 1984 and 2008. The only two occasions when output gap seems to be a lot lower than that suggested by the conventional Taylor rule is prior to 1990 and

between 2004 and 2006. However, the interesting finding with respect to output gap is seen during the Great Recession period. The fall in stock prices after the bust of the housing bubble has been considered to have exacerbated the severity of the recession. Our finding suggests that had interest rates been higher in response to rising stock prices, prior to the Great recession, the fall in output would have been much lower. This is the main result of this paper. To further explore, why this would have been the case, we can have a closer look at the graph for stock price gap as given in figure B.5. The graph provides a clear picture of how the volatility in the stock price gap would have been lower with higher interest rates. It also suggests that had the Federal Reserve raised their policy rate in response to rising stock prices, the boom-bust cycle of stock prices would have been substantially reduced. For example, as the figure suggests, the exuberance of the dotcom in the late 1990s and the boom in stock prices associated with the housing market in the mid 2000s would have been milder.

Now turning to the comparison between the two rules as given in Table B.2 that also reports the descriptive statistics for the data, we find support for our graphical analysis. We find that the Taylor rule with stock prices would have performed better in terms of stabilizing output gap. The mean of output gap constructed with the Taylor rule with stock price gap is higher at 0.51 in comparison with the mean of -0.26 associated with the traditional Taylor rule. In fact, we find a stark difference between the variance of the two rules. The variance of output gap is significantly lower in our counterfactual case implying lower volatility. This result is supported by the descriptive statistics of the stock price gap series. The stock price gap series obtained in our counterfactual experiment imply a much lower variance of 96.04 as compared to the variance of 122.32 as implied by the traditional Taylor rule. The mean of the stock price gap series is also lower.

When the Federal Reserve targets stock price misalignments, we would expect the interest rates to be higher on average and become more volatile. This may be at odds with the interest rate "smoothing" objective of the central bank as discussed in Filardo (2001). However, as Cecchetti et al. (2000) have argued, if the objective of the central bank is to "lean against the wind" to pressures blowing from the stock market, it might help in anchoring expectations of the private sector and the public, as it might be perceived as an action that would result in greater macroeconomic stability in the future. In table B.2, we find that in our counterfactual experiment, interest rates have a higher mean and variance of 5.36 and 7.95 respectively as compared to the interest rates implied by the traditional Taylor rule counterpart.

If we compare the two rules on the basis of which caters best to price stability objective of the central bank, we find that the traditional Taylor rule performs a little better. It implies a higher mean of 2.26 for inflation with a lower variance of 1.69 as compared to its counterfactual counterpart. However, both rules suggest that the mean of inflation would have been pretty close to the inflation target of 2% of the Federal Reserve.

Intuitively, these results can be justified by comparing the two models. The traditional Taylor rule suggests that policy rate is set in response to inflation and output gap only. This means, in the face of asset price misalignments, interest rates are not changed unless these misalignments exert some pressure on output or inflation. In fact, as the study by Borio and Lowe (2002) suggested, in most industrialized countries, asset price misalignments coexisted with low and stable inflation. Basically, the expansionary effect that rising stock prices exert on output will not be counteracted in the traditional Taylor rule. This gives rise to a more pronounced boom-bust cycle in the stock price gap series and is eventually, translated into a more volatile output gap series when asset price misalignments exist.

On the other hand, the Taylor rule with the stock price gap dampens the effect of asset price misalignments. The rule suggests that interest rates would rise when stock prices are above warranted levels and fall when stock prices are below warranted levels. Therefore, this results in making the real stock price gap series less volatile. Our stock price dynamics equation suggests that the path of real stock price gap depends negatively on the policy rate. With interest rates rising in response to rising stock prices as suggested by the counterfactual Taylor rule, there is a downward pressure exerted on real stock prices which further dampens the expansionary effect of stock price misalignments on output. Thus, we see that in terms of volatility our counterfactual output gap series is less volatile than that implied by its traditional Taylor rule counterpart.

Keeping the results of this paper in mind, we have good reason to believe that if the Fed had raised interest rates in response to rising stock prices, the severity of the Great Recession could have been avoided.

2.8 Conclusion

The 2008-2009 global financial crisis has intensified the interest in exploring the interactions between monetary policy asset price fluctuations and the real economy. This paper aimed to analyse the response of the Federal Reserve's monetary policy to stock price fluctuations and explore whether a systematic response of the Federal Reserve to stock price misalignments would have been beneficial in terms of stabilizing output in the Great moderation period. We have studied these questions by employing a small structural New Keynesian model with asset prices. We found that in the last three decades, the response of the Federal Reserve to the stock market has been negligible. In the light of this result, our paper thus presented a counterfactual exercise in which we discussed the implications

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of the Fed following a counterfactual interest rate rule that suggests that policy is set not only in response to inflation and output gap but also to stock price misalignments.

We found that in terms of overall macroeconomic stability, this rule would have performed better as compared to a rule that only targeted inflation and output gap. Our results show that if the Fed raised interest rates prior to crashes, in particular prior to the Great Recession, the loss and variability in output would have been much lower because the boom-bust cycle of stock prices would have been substantially reduced. Surprisingly, higher interest rates would not have been associated with a decrease in average output and inflation would have been lower as well. These results indicate that the severity of the Great Recession could have been avoided by raising interest rates when stock price misalignments were substantial. Our exercise is similar to Taylor (2007), who has shown that the boom-bust in housing prices would have been lower had interest rates been higher when house prices were appreciating. His study also suggested how the Fed, by keeping interest rates too low for too long had encouraged the housing boom. We have investigated the ramifications of a policy that responds to asset price misalignments using the classic methodology of a counterfactual scenario. Our study is important from a future policy perspective and supports the notion that a preemptive action by the Fed, in particular, by altering short-term interest rates in the face of asset price misalignments could be beneficial in avoiding severe dislocations in real activity in the future. As a future exercise, we would like to investigate time varying monetary policy rules by incorporating asset price misalignments in the equity and real estate sectors. The idea behind this exercise is that there may not be a need for the Fed to respond to asset price misalignments on a permanent basis. It seems more plausible that when a response is warranted, it is only when asset price misalignments are substantial suggesting an asymmetric or time varying response.
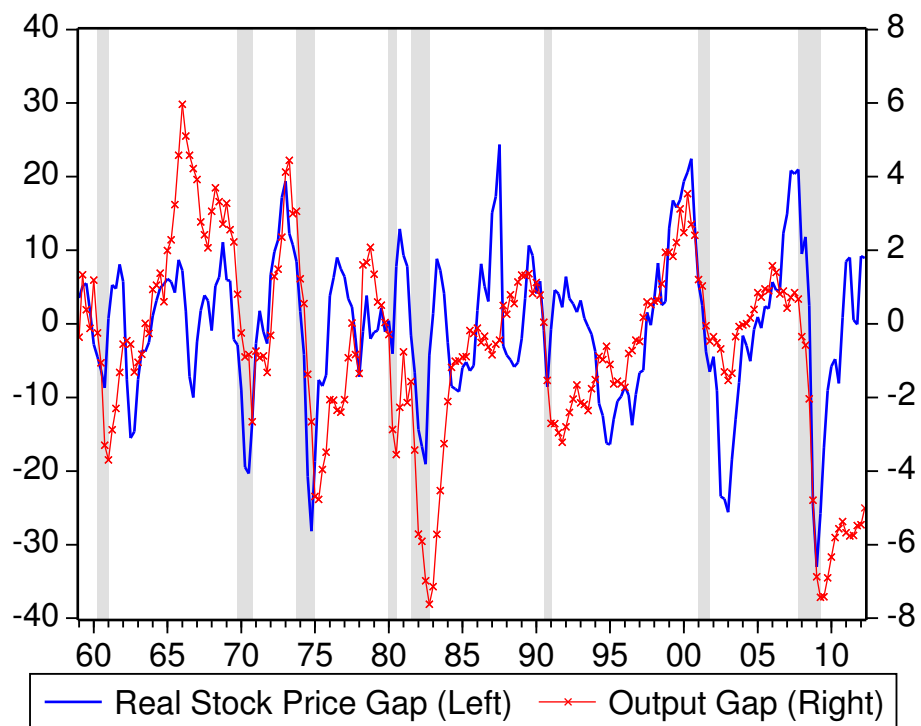
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Appendix B

Appendix

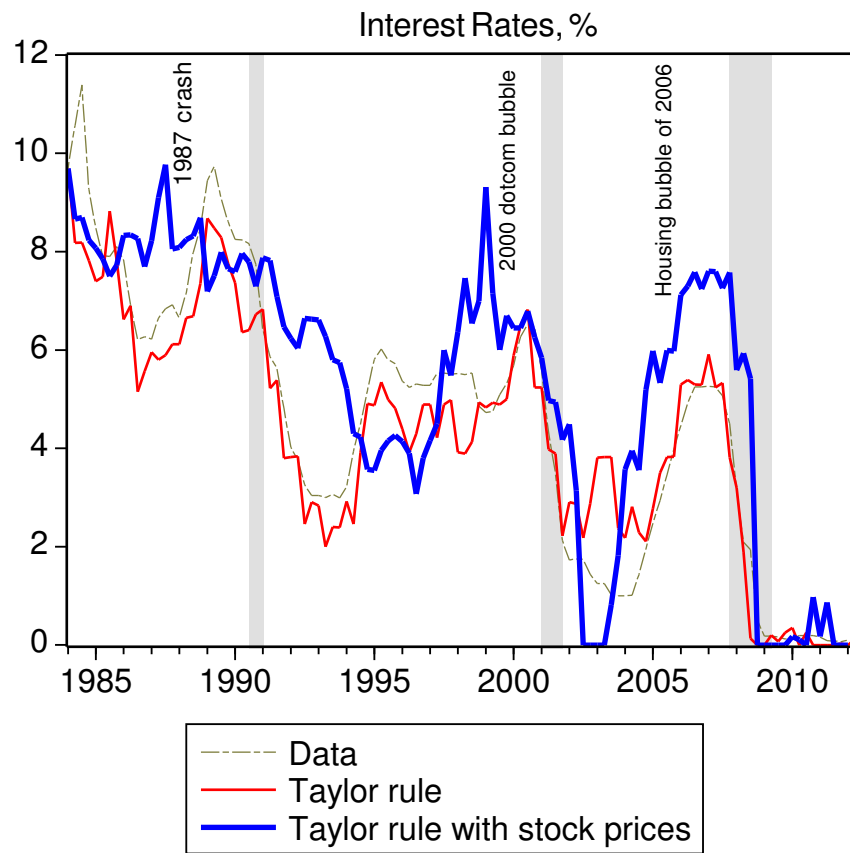Figure B.1:   The gray shaded bars represent the NBER recessions

Figure B.2: Counterfactual experiment for interest rates
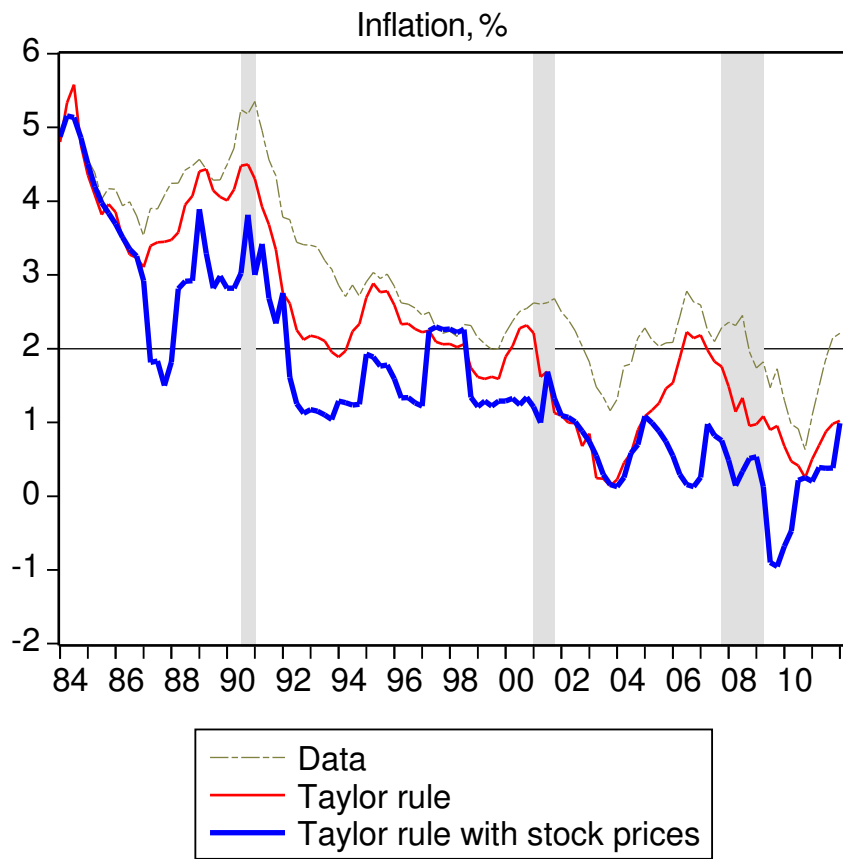
Figure B.3: Counterfactual experiment for inflation
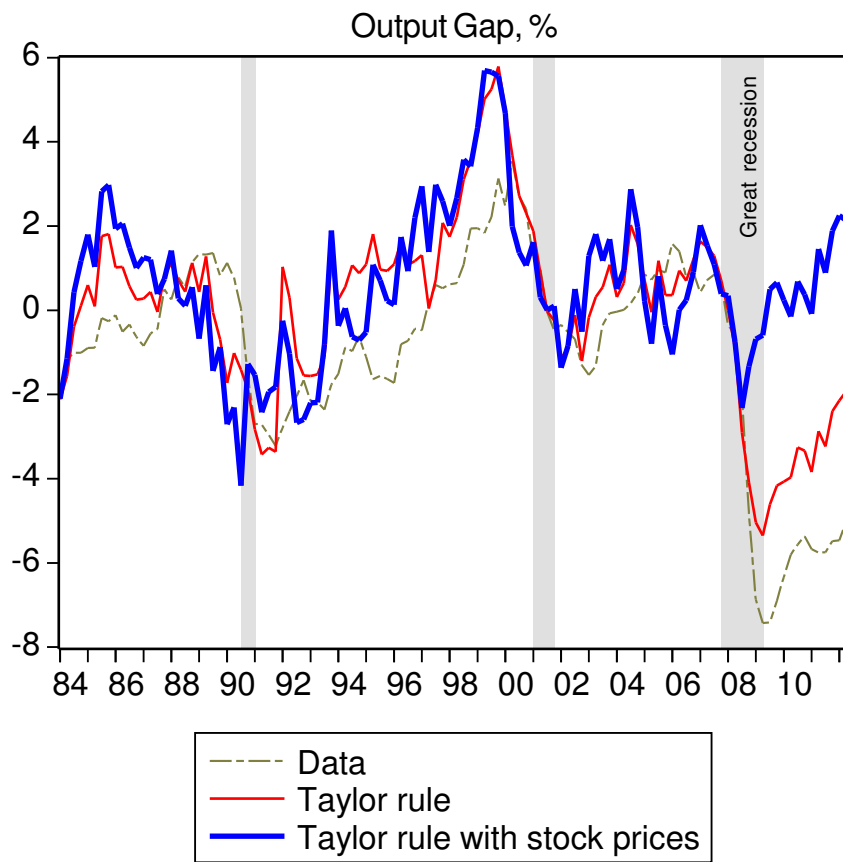
Figure B.4: Counterfactual experiment for output gap

Standard Deviations	1959-2012	1959-1979	1984-2012
Real Stock price gap	10.19	8.77	11.21
Output Gap	2.65	2.44	2.37
Inflation	2.5	2.72	1.13

Table B.1: Descriptive statistics

Series	Output Gap		Inflation		Interest Rates		Real Stock Price Gap	
	Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance
Taylor Rule	-0.26	5.12	2.26	1.69	4.31	5.66	-0.9	122.32
Taylor Rule with SP	0.51	3.27	1.62	1.75	5.36	7.95	-3.2	96.04
Data	-0.92	5.71	2.9	1.28	4.55	7.89	-0.34	125.44

Table B.2: Mean and variance comparison

Figure B.5: Counterfactual experiment for stock price gap

B.1 Consumption index

We define the consumption index C_t by

$$C_t \equiv \left(\int_0^1 C_t(i)^{1-\frac{1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}}$$

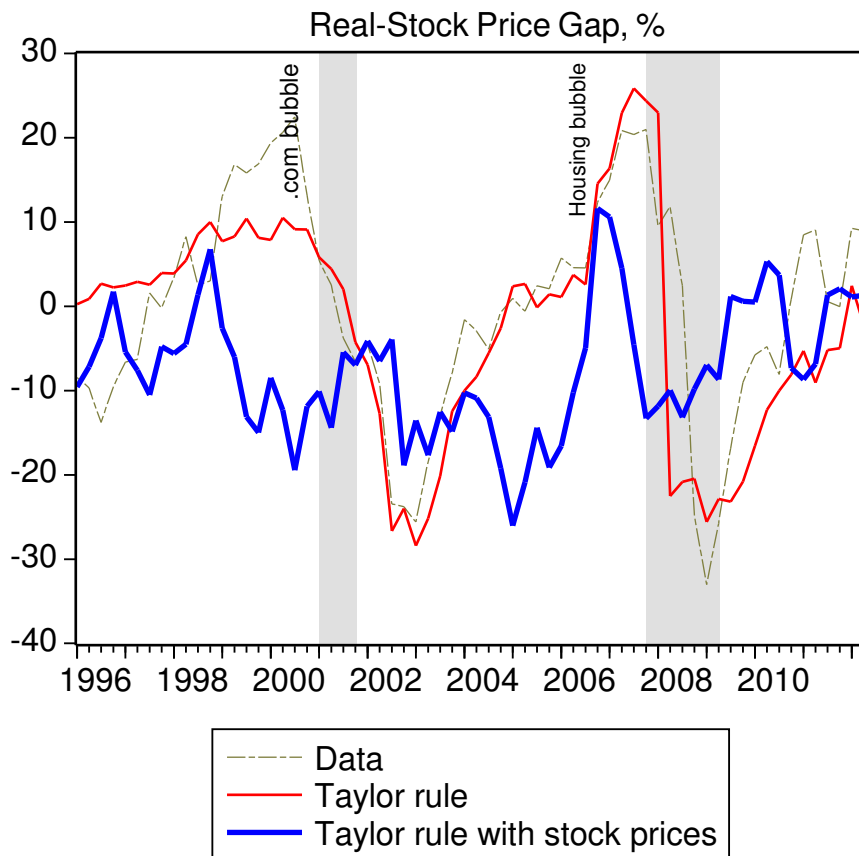where $C_t(i)$ represents the quantity of good i consumed by the household in period t. We assume the existence of a continuum of goods represented by the interval [0, 1]. The consumption index can be maximized for any given level of expenditure

$$\int_0^1 P_t(i)C_t(i)di \equiv Z_t.$$

Following Galí (2008), the solution to this problem gives

$$\int_0^1 P_t(i)C_t(i)di = P_tC_t. \tag{B.1}$$

$\forall i \in [0,1]$ and where the aggregate price level P_t is defined as

$$P_t \equiv \left[\int_0^1 P_t(i)^{1-\varepsilon} di \right]^{\frac{1}{1-\varepsilon}}. \tag{B.2}$$

B.2 Dynamics of Aggregate Price level

We assume that a fraction of firms represented as $F(t) \subset [0,1]$ do not reoptimize their posted price in period t. Defining the aggregate price level as in (B.2) and the using fact that all firms resetting prices will choose an identical price[1] P_t^*,

$$P_t = \left[\int_{F(t)} P_{t-1}(i)^{1-\varepsilon} di + (1-\theta)(P_t^*)^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}}.$$

---

[1]This result arises because all firms face the same problem

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Since the fraction of firms not readjusting their price in period t corresponds to a total mass reduced to θ, we have

$$P_t = \left[\theta P_{t-1}(i)^{1-\varepsilon} + (1-\theta)(P_t^*)^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}}.$$

Dividing both sides of the above equation by P_{t-1} and defining $\Pi_t \equiv \frac{P_t}{P_{t-1}}$ as the gross inflation rate between t-1 and t,

$$\Pi_t^{1-\varepsilon} = \theta + (1-\theta)\left(\frac{P_t^*}{P_{t-1}}\right)^{1-\varepsilon} \tag{B.3}$$

In a steady state with zero inflation we have $P_t^* = P_t = P_{t-1}$ $\forall$t. Log-linearizing (B.3) around $\Pi_t = 1$ gives

$$\pi_t = (1-\theta)(p_t^* - p_{t-1}) \tag{B.4}$$

where the inflation rate is defined as $\pi_t = \Pi_t - 1$. The above equation also suggests that in our model, inflation is a result of firms readjusting their prices in any given period choose a price that differs from the economy's average price in the previous period. This evolution of inflation can be explained further if we analyse optimal price setting decisions of firms.

B.3 Price setting

The optimization problem of the firm is solved and leads to a first-order Taylor expansion around a zero-inflation steady state[2]

$$p_t^* - p_{t-1} = (1 - \beta\theta) \sum_{k=0}^{\infty} (\beta\theta)^k E_t[\widehat{mc}_{t+k|t} + (p_{t+k} - p_{t-1})] \tag{B.5}$$

where $\widehat{mc}_{t+k|t} = mc_{t+k|t} - mc$ denotes the log deviation of marginal cost from its steady state value $mc = -\mu$, and $\mu = log(\frac{\varepsilon}{\varepsilon-1})$ represents the log of the desired gross markup.

B.4 Derivation of the IS and Phillips curve

We follow Galí (2008) and Woodford (2003) to derive the IS and Phillips curves. We can combine the goods market clearing condition with the consumer's Euler equation to yield the equilibrium condition

$$y_t = E_t y_{t+1} - \frac{1}{\sigma}(i_t - E_t\pi_{t+1} - \rho) \tag{B.6}$$

By using the production function as in (2.7) and taking logs, we can write the approximate relation between aggregate output, employment and technology by

$$y_t = a_t + (1 - \alpha)n_t \tag{B.7}$$

We derive an expression for the individual firm's marginal cost in terms of the economy's average real marginal cost. We can define the economy's average real marginal cost[3] by

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[2]For more details, see Galí (2008).
[3]The lowercase variables denote the logs of the respective variables from the steady state

$$mc_t = (w_t - p_t) - mpn_t$$

$$= (w_t - p_t) - (a_t - \alpha n_t) - log(1 - \alpha)$$

$$= (w_t - p_t) - \frac{1}{1 - \alpha}(a_t - \alpha y_t) - log(1 - \alpha)$$

$\forall t$, where we use (B.7) to derive the last equation.

Since

$$mc_{t+k|t} = (w_{t+k} - p_{t+k}) - mpn_{t+k|t}$$

$$= (w_{t+k} - p_{t+k}) - \frac{1}{1 - \alpha}(a_{t+k} - \alpha y_{t+k}) - log(1 - \alpha)$$

$$= mc_{t+k} + \frac{\alpha}{1 - \alpha}(y_{t+k} - y_{t+k})$$

$$= mc_{t+k} + \frac{\alpha\varepsilon}{1 - \alpha}(p_t^* - p_{t+k}) \tag{B.8}$$

The last equation is derived by substituting for the demand elasticity, $-\varepsilon = \frac{\Delta y}{\Delta p}$ and the fact that the market clearing condition suggests $c_t = y_t$. Substituting (B.8) into (B.5) gives

$$p_t^* - p_{t-1} = (1 - \beta\theta)\sum_{k=0}^{\infty}(\beta\theta)^k E_t[\Theta\widehat{mc}_{t+k} + (p_{t+k} - p_{t-1})]$$

$$= (1 - \beta\theta)\Theta\sum_{k=0}^{\infty}(\beta\theta)^k E_t[\widehat{mc}_{t+k} + \sum_{k=0}^{\infty}(\beta\theta)^k E_t\pi_{t+k}$$

$$= \beta\theta E_t p_{t+1}^* - p_t + (1 - \beta\theta)\Theta\widehat{mc}_t + \pi_t \tag{B.9}$$

where $\Theta = \frac{1-\alpha}{1-\alpha+\alpha\varepsilon}$ and the last equation is a compact representation of the discounted sum in previous equations. Now combining (B.4) and (B.9) yields the inflation

equation

$$\pi_t = \beta E_t \pi_{t+1} + \lambda \widehat{mc}_t \qquad (B.10)$$

where $\lambda \equiv \frac{(1-\theta)(1-\beta\theta)}{\theta}\Theta$ is strictly decreasing in the index of price stickiness θ, in the measure of decreasing returns α and in the demand elasticity ε. Iterating the equation forward, inflation can be written as the discounted sum of current and expected future deviations of marginal costs from steady state

$$\pi_t = \lambda \sum_{k=0}^{\infty} \beta^k E_t \widehat{mc}_{t+k}$$

If we define the average markup as $\mu_t = -mc_t$, inflation will be higher when firms expect average markups to be below their steady state or desired level μ. This will encourage firms that are willing to reoptimize prices to choose a price above the economy's average price level to realign their markup closer to its desired level. In this framework, inflation results from the price-setting decisions by firms, which adjust their prices looking at current and expected costs.

The relationship between the economy's real marginal cost and a measure of aggregate economic activity can be derived by using the household's optimality condition and the approximate aggregate production relation given by (B.7) writing the real marginal cost as

$$
\begin{aligned}
mc_t &= (w_t - p_t) - mpn_t \\
&= (\sigma y_t + \phi n_t) - (y_t - n_t) - log(1-\alpha) \\
&= \left(\sigma + \frac{\phi + \alpha}{1 - \alpha}\right) y_t - \frac{1 + \phi}{1 - \alpha} a_t - log(1-\alpha) \qquad (B.11)
\end{aligned}
$$

Since under the case of flexible prices, real marginal cost is constant as denoted by $mc = -\mu_t$, we can further derive the natural level of output under flexible prices

$$mc_t = \left(\sigma + \frac{\phi + \alpha}{1 - \alpha}\right) y_t^n - \frac{1 + \phi}{1 - \alpha} a_t - log(1 - \alpha) \tag{B.12}$$

where the flexible level of output is given by

$$y_t^n = \psi_{ya}^n a_t - \vartheta_y^n$$

where $\vartheta_y^n \equiv \frac{(1-\alpha)(\mu - log(1-\alpha))}{\sigma(1-\alpha) + \phi + \alpha} > 0$ and $\psi_{ya}^n \equiv \frac{1+\phi}{\sigma(1-\alpha) + \phi + \alpha}$. Subtracting (B.12) from (B.11) we can find an expression for the log deviation of real marginal cost given by

$$\widehat{mc}_t = \left(\sigma + \frac{\phi + \alpha}{1 - \alpha}\right)(y_t - y_t^n) \tag{B.13}$$

The above equation suggests that the log deviation of real marginal cost is proportional to the log deviation of output from its flexible price counterpart called output gap. We can denote output gap as $\widetilde{y}_t \equiv y_t - y_t^n$. By combining (B.13) with (B.10) we can obtain that relates inflation to its one period ahead forecast and output gap

$$\pi_t = \beta E_t \pi_{t+1} + \kappa \widetilde{y}_t \tag{B.14}$$

where $\kappa \equiv \lambda \left(\sigma + \frac{\phi + \alpha}{1 - \alpha}\right)$. Equation (2.11) is our New Keynesian Phillips curve(NKPC) that determines inflation given a path for output gap.

The Dynamic IS curve (DIS)with stock prices is obtained by rewriting (B.6) in terms of the output gap and augmenting it to allow for a feedback mechanism that suggests

that stock prices affect aggregate demand[4] gives

$$\widetilde{y}_t = E_t \widetilde{y}_{t+1} - \frac{1}{\sigma}(i_t - E_t \pi_{t+1} - r_t^n) + \zeta s_t \tag{B.15}$$

where s_t is the real stock price gap as described in the next section and the evolution of the natural rate of interest is given by

$$\begin{aligned} r_t^n &= \rho + \sigma E_t \Delta y_{t+1}^n \\ &= \rho + \sigma \psi_{ya}^n E_t \Delta a_{t+1}. \end{aligned}$$

B.5 Consumer's Optimization Problem

$$max \quad E_t \sum_{k=0}^{\infty} \beta^k U(C_{t+k}, N_{t+k})$$

subject to

$$P_t C_t + Q_t B_t + P_t P_t^s S_t \leq B_{t-1} + W_t N_t - T_t + P_t P_t^s S_{t-1} + P_t D_t S_{t-1} \tag{B.16}$$

Let λ_t be the Lagrange multiplier on the budget constraint. We obtain the first-order conditions with respect to C_t, N_t, B_t and S_t:

$$U_{C,t} + P_t \lambda_t = 0 \tag{B.17}$$

$$U_{N,t} + W_t \lambda_t = 0 \tag{B.18}$$

$$\lambda_t Q_t - \beta E_t \lambda_{t+1} = 0 \tag{B.19}$$

$$\lambda_t P_t P_t^s - \beta E_t \lambda_{t+1}(P_{t+1} P_{t+1}^s + P_{t+1} D_{t+1}) = 0 \tag{B.20}$$

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[4]Filardo (2001) has suggested a similar representation in terms of growth rates of stock prices affecting growth rate of output. Here we have an analogous representation in terms of real stock price gap affecting output gap.

Equation (B.17) and (B.19) give the Euler equation. Equation (B.18) and (B.20) determine the labor supply and the real return on the financial asset. The optimality conditions implied by the maximization of (2.1) with respect to (B.16) are given by

$$-\frac{U_{N,t}}{U_{C,t}} = \frac{W_t}{P_t} \tag{B.21}$$

$$Q_t = \beta E_t[\frac{U_{C,t+1}}{U_{C,t}} \frac{P_t}{P_{t+1}}] \tag{B.22}$$

for $t = 0, 1, 2....$Assuming the period utility takes the form as described by (2.3), we can write (B.21) and (B.22) as

$$\frac{W_t}{P_t} = C_t^\sigma N_t^\phi$$

The log-linear version of this intra temporal optimality condition[5] can be written as

$$w_t - p_t = \sigma c_t + \phi n_t$$

The euler equation can be written as

$$Q_t = \beta E_t \left\{ \left(\frac{C_{t+1}}{C_t}\right)^{-\sigma} \frac{P_t}{P_{t+1}} \right\}$$

Taking logs on both sides, yields

$$log(Q_t) = log(\beta) - \sigma E_t[\sigma(c_{t+1} - c_t) + p_t - p_{t+1}]$$

$$-i_t = -\rho - \sigma E_t(\Delta c_{t+1}) - E_t\pi_{t+1}$$

$$c_t = E_t c_{t+1} - \frac{1}{\sigma}(i_t - E_t\pi_{t+1} - \rho)$$

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[5]The lowercase variables denote the logs of the respective variables from the steady state(i.e. $x_t \equiv log(X_t/X)$

where $i_t \equiv -log(Q_t)$ is the short term nominal rate and $\rho \equiv -log(\beta)$ is the discount rate. Equation (B.23) is the log-linearized euler equation.

Equation (B.20) yields

$$1 = E_t[\beta \frac{U_{C,t+1}}{U_{C,t}} \frac{P^s_{t+1} + D_{t+1}}{P^s_t}] \qquad (B.23)$$

We can rewrite the above equation as

$$U_{C,t}P^s_t = \beta E_t[U_{C,t+1}(P^s_{t+1} + D_{t+1})]$$

where the left hand-side is the cost of buying a unit of the asset, while the right hand side is the expected value of future consumption benefit derived from the dividend and capital value of the financial asset.

Thus, we have

$$P^s_t = E_t[Q_t \frac{P_{t+1}}{P_t}(P^s_{t+1} + D_{t+1})]$$

We can re-write the above equation[6] as

$$P^s_t = Q_t E_t[\Pi_{t+1}(P^s_{t+1} + D_{t+1})] - P^s_t \Lambda_t$$

where Λ_t is defined as the negative covariance between the stochastic discount factor and the nominal rate of return on stocks that generates a risk premium:

$$E_t[\Pi_{t+1}(P^s_{t+1} + D_{t+1})] - (1 + i_t) = (1 + i_t)\Lambda_t$$

We follow Nisticò (2012) to linearize the equation with stock-price dynamics and use the assumption of an exogenous stochastic component of the equity premium, to account

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[6]We use E[ab]=E[a]E[b]+cov[a,b]

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for the observed average premium and fluctuations that are non-fundamental as in Smets and Wouters (2003)

$$\Lambda_t \equiv \Lambda exp(e_t)$$

Equilibrium in the long run i.e. under a zero inflation steady state suggests that $\beta = 1/(1 + i)$ and $\frac{D}{(1+i)P_t^s} = 1 + \Lambda - \beta$. Using these relations, we are able to log-linearize our stock price dynamics equation to yield,

$$(1 + \Lambda)p_t^s = \frac{1}{1 + i}E_t p_{t+1}^s + \frac{D}{(1 + i)P_t^s}E_t d_{t+1} - (1 + \Lambda)(i_t - E_t\pi_{t+1} - r_t^n) - \Lambda e_t \quad \text{(B.24)}$$

We can also write the dynamics of the dividends by making use of the production function (2.7) and equation with real marginal costs given by (B.11) as,

$$d_t = y_t - \frac{WN}{PD}mc_t$$

Using the definition of output gap, marginal costs as a function of output gap as in (B.12) and (B.24), we can write

$$p_t^s = \frac{\beta}{1 + \Lambda}E_t p_{t+1}^s - \gamma E_t \tilde{y}_{t+1} - \frac{1}{\sigma}(i_t - E_t\pi_{t+1} - \rho) + \frac{1 + \Lambda - \beta}{1 + \Lambda}E_t y_{t+1}^n - \frac{\Lambda}{1 + \Lambda}e_t \quad \text{(B.25)}$$

where $\gamma = \frac{\beta}{1+\Lambda}\frac{1+\phi}{\mu}\frac{Y}{P_t^s} - (1 + \Lambda - \beta)$. We can also write the equation governing stock price dynamics under flexible prices represented by p_t^{sn} as

$$p_t^{sn} = \frac{\beta}{1 + \Lambda}E_t p_{t+1}^{sn} - \frac{1}{\sigma}(r_t^n - \rho) + \frac{1 + \Lambda - \beta}{1 + \Lambda}E_t y_{t+1}^n - \frac{\Lambda}{1 + \Lambda}e_t \quad \text{(B.26)}$$

Subtracting (B.26) from (B.25), we can now define the deviation of actual real stock prices from their flexible price level as $s_t = p_t^s - p_t^{sn}$. Thus, we have

$$s_t = \frac{\beta}{1 + \Lambda} E_t s_{t+1} - \gamma E_t \tilde{y}_{t+1} - \frac{1}{\sigma}(i_t - E_t \pi_{t+1} - r_t^n) \tag{B.27}$$

We can simplify and rewrite the above equation as

$$s_t = \beta E_t s_{t+1} - \gamma E_t \tilde{y}_{t+1} - \frac{1}{\sigma}(i_t - E_t \pi_{t+1} - r_t^n) \tag{B.28}$$

since $\Lambda \approx 0.01$ that implies an annualized steady state equity premium of 6.2%, Nisticò (2012).

Chapter 3

Credit Spreads, Asset Prices and Monetary Policy[1]

3.1   Introduction

Credit spreads are a reflection of market participants' attitudes towards risk, and are an important source as well as amplifying mechanism of business cycle fluctuations. The classic work by Bernanke et al. (1999b) has shown, using the financial accelerator, that credit spreads arise from frictions in financial markets and serve as an important business cycle propagation mechanism. The recent financial crisis that was followed by a severe recession, was largely characterized by credit spreads spiking dramatically. This recent phenomena has generated an increased interest in studying the role that credit spreads play in the macroeconomy and have sparked a debate over the appropriate monetary policy response to movements in credit spreads. Christiano et al. (2007) and Christiano et al. (2010) have discussed how a response to credit growth that is associated with asset booms

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[1]This chapter is a product of discussions and with Marcelle Chauvet and is a version of our prospective joint work.

may be welfare enhancing for the macroeconomy. Taylor (2008) and McCulley and Toloui (2008) argue that it is the real interest rates paid by borrowers, not the rates controlled by the central bank, that are a key determinant of economic activity. In fact, they propose that the intercept term in a Taylor rule, Taylor (1993), for monetary policy should be adjusted downward in proportion to observed increases in spreads[2]. Cúrdia and Woodford (2009) assess the degree to which a modification of the classic Taylor rule to incorporate credit spreads would generally improve the way in which the economy responds to disturbances of various sorts, including in particular to those originating in the financial sector[3] In another study, Teranishi (2012), shows that a Taylor rule that includes a response to the credit spread is theoretically optimal monetary policy under heterogeneous loan contracts. This optimal response is however ambiguous and depends on the financial market structure.

This paper asks three related questions. First, to what extent has the Federal Reserve adjusted interest rates in response to movements in credit spreads in the past and whether this response has evolved overtime. Secondly, how does the presence of financial intermediaries that are a source of credit growth, contribute to the fluctuations in the macroeconomy in the face of a monetary policy shock. Third, what effect does a financial shock that tends to increase credit spreads have on macro variables in the economy? The second question has been answered using the financial accelerator framework as in Bernanke et al. (1999b) and Iacoviello (2005). However, these studies assume that credit spreads arise due to asymmetric information in financial markets. We turn away from the financial accelerator framework in this paper and focus on how the dynamics of different interest rates contribute to fluctuations in macro variables[4]

[2]Taylor and Williams (2008) claim that the spreads, measured by the differences between LIBOR rate and Fed-funds rates, rise quickly during financial crises.

[3]They find that, an adjustment for variations in credit spreads can improve upon the standard Taylor rule, but the optimal size of adjustment depends on the source of the variation in credit spreads.

[4]Christiano et al. (2011) have also shown how the dynamics of different interest rates contribute signifi-

Most of the New Keynesian literature used in both theoretical analyses of optimal monetary policy and in alternative specifications of policy rules are unsuitable for the analysis of such issues, because they abstract altogether from the economic role of financial intermediation. In these studies, it is a common practice to analyze monetary policy with a single interest rate contrary to what Taylor (2008) has argued. Therefore, an obvious fallback is that we cannot analyze the implications of responding to variations in credit spreads on the macroeconomy. In order to address the questions in this paper, we extend the standard New Kenynesian model to include the stock market and financial intermediaries. Financial intermediaries reallocate funds from the households to the firms. However, different from the previous literature, we assume that firms finance their investment from two sources: bank loans and retained earnings. This structure gives rise to a wedge in the interest rates: the firms borrow from banks at the bank loan rate and households deposit funds in the banks at a deposit rate. We also incorporate a financial market shock[5] into our model that can potentially drive up the lending rate and thus increase the credit spread in times of financial stress. Since we assume that firms require heterogenous funds to finance their investments and a banking sector that can be subject to a financial shock, different dynamics of the interest rates emerge. In comparison to a standard model without a financial sector, the effect of a financial shock in our model will impact investment decisions that are linked to the lending rate.

Our main findings are as follows. For the Great Inflation period between 1959 and 1979 we find a very weak negative response of the Fed policy to the credit spread. However, for the Great Moderation period (post-1983), we find a very strong response of the Fed policy to credit spreads. This is in line with Taylor (2008) who argues that in

cantly to economic outcomes.

[5]Such a shock may come from changes in labor productivity, liquidity management, risk-rating strategies, and a broadly interpreted default risk.

the US the Federal Reserve Board (FRB) has reacted negatively to the credit spread in the money market to stimulate the economy. In particular, our result supports the view that the spread-adjusted Taylor rule can well explain the easing of monetary policy by the Fed in response to the subprime mortgage crisis. We also find that the transmission of a monetary policy shock under a model with financial intermediaries makes most macro variables like consumption, inflation, equity premium more volatile. In fact, the policy rate increases relatively more in response to a monetary policy shock in a model with financial intermediaries. A financial shock that causes credit spreads to rise results in a decrease in bank loans that lower investment and thus output. Consumption and inflation is lower as result. Firms substitute retained earnings for bank loans to finance their investment that drives up the equity return.

The organization of the paper is as follows: Section 3.2 presents New Keynesian model with financial intermediaries; Section 3.3 explains the estimation procedure; Section 3.4 presents empirical results from our estimations and Section 3.5 presents the analysis of the impulse responses to monetary policy and financial shocks. Section 3.6 concludes. All derivations and graphs can be found in the Appendix C.

3.2   Model

The model economy consists of a representative household, banks, a continuum of firms producing final goods, a government and a monetary authority. Households supply labor to firms, consume goods, save in banks, hold risk-free bonds and risky assets. Firms hire labor and use capital to produce and sell differentiated products in monopolistically competitive goods markets. A representative consumer gets income from five sources: the wages from labor supply, the dividends of equity shares invested last period, the returns of

bond holding and deposits. Firms finance a new investment by both retained earnings and

bank loans. A continuum of monopolistically competitive firms use labor effort and capital

to produce final goods. Households and firms behave optimally: households maximize the

expected present value of utility whereas firms maximize profits. Banks provide deposit

services to the consumer and make loans to firms. The central bank uses a monetary rule

to control the policy interest rate. The monetary policy block of the model consists of a

central bank that sets the nominal rate of interest. Our model is inspired by Galí (2008),

Walsh (2003).

3.2.1 Households

We assume a representative infinitely-lived household, seeking to maximize

$$E_t \sum_{k=0}^{\infty} \beta^k U(C_{t+k}, N_{t+k}) \tag{3.1}$$

where $U(C_t, N_t)$ is the period utility function and consumers discount utility at

the rate of $\beta < 1$.

We assume the existence of a continuum of goods[6] represented by the interval $[0, 1]$.

The household decides how to allocate its income on the different goods. This requires that

the income index Y_t be maximized for any given level of expenditures. Conditional on this

optimal behavior of households, the budget constraint takes the form

$$P_t C_t + Q_t B_t + \widehat{P}_t^s S_t + J_t + T_t \leq B_{t-1} + W_t N_t + \widehat{P}_t^s S_{t-1} + P_t D_t S_{t-1} + \Pi(B) + R_t^j J_{t-1} \tag{3.2}$$

for t=0,1,2..., where P_t is the aggregate price index[7], W_t is the nominal wage rate,

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[6]The consumption index is given by $C_t \equiv \left(\int_0^1 C_t(i)^{1-\frac{1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}}$ where $\varepsilon > 1$ is the elasticity of substitution among differentiated goods.

[7]The aggregate price index is given by $P_t \equiv \left[\int_0^1 P_t(i)^{1-\varepsilon} di \right]^{\frac{1}{1-\varepsilon}}$

received by supplying labor N_t. Households can invest in two types of financial assets: bonds and equity shares which are issued by monopolistically competitive firms, to which they also supply labor[8]. In addition, households deposit J_t funds in the bank and receive a return of R_t^j on the deposits from the last period. The quantity of one-period, nominally riskless discount bonds purchased in time period t is represented by B_t and they mature in the subsequent period, $t+1$. Each bond pays one unit of money at maturity and its price is given by Q_t. The nominal interest rate is given by $i_t = -log(Q_t)$. The nominal lump-sum taxes are represented by T_t. The nominal price of the quantity of the risky financial asset S_t is given by $\widehat{P}_t^s = P_t P_t^s$ where P_t^s is the real price (in terms of the market basket of consumption goods given by the consumption index C_t) of the financial asset. The real dividends denoted by D_t are paid at time t to holders of the asset at $t-1$.

The regular assumptions apply to the utility function[9]

Under the assumption of period utility given by

$$U(C_t, N_t) = \frac{C_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\phi}}{1+\phi} \tag{3.3}$$

consumption, labor, bond and financial asset holdings are chosen to maximize (3.1) subject to (3.2) and the solvency condition. The parameter σ is the coefficient of relative risk aversion of households (also, the inverse of the intertemporal elasticity of substitution) and ϕ is the inverse of the elasticity of work effort with respect to the real wage. The intra

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[8]We assume a cashless economy following Woodford (2003)

[9]The expected value of utility where the period utility function is given by $U(C_t, N_t)$ is assumed to be twice continuously differentiable, with $U_{c,t} > 0$, $U_{cc,t} \leq 0$, $U_{cc,t} \leq 0$, $U_{n,t} \leq 0$ and $U_{nn,t} \leq 0$. This implies that the marginal utility of consumption, given by $U_{c,t}$, is positive and nonincreasing and the marginal disutility from working (labor), given by $-U_{n,t}$, is positive and nondecreasing.

and inter-temporal optimality conditions are given by

$$\frac{W_t}{P_t} = C_t^{\sigma} N_t^{\phi} \tag{3.4}$$

$$Q_t = \beta E_t \left\{ \left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} \frac{P_t}{P_{t+1}} \right\} \tag{3.5}$$

$$P_t P_t^s = E_t [Q_t P_{t+1}(P_{t+1}^s + D_{t+1})] \tag{3.6}$$

Equation (C.11) gives the intra temporal optimality condition that governs the trade-off between consumption and leisure and can be interpreted as the labor supply schedule, determining the quantity of labor supplied as a function of the real wage, given the marginal utility of consumption. Equation (C.12) yields the familiar euler equation and requires that in equilibrium, the marginal utility of consumption inter-temporally equalizes through the adjustment of the real interest rate. Equation (3.6) defines the nominal price of total equity shares as the discounted value of the future expected payoffs.

3.2.2 Firms

We assume a continuum of monopolistically competitive firms indexed by $i \in [0, 1]$ which produce a continuum of differentiated goods using identical technology, represented by the production function

$$Y_t(i) = A_t K_t(i)^{\alpha} N_t(i)^{1-\alpha} \tag{3.7}$$

where A_t represents the level of technology, assumed to be common to all firms and to evolve exogenously over time and $N_t(i)$ represents labor. Firms face identical de-

mand schedules[10] given by $Y_t(i) = (\frac{P_t(i)}{P_t})^{-\varepsilon} Y_t$ where aggregate output is given by $Y_t \equiv$

$\left(\int_0^1 Y_t(i)^{1-\frac{1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}}$ and take the aggregate price level P_t and aggregate consumption index

C_t as given. Here, we follow the set up proposed by Vu (2010). The next period capital

stock, K_{t+1} is based on the current capital stock depreciated at rate δ and the current

investment flow.

$$K_{t+1} = (1 - \delta)K_t + I_t$$

It is assumed that the period-t investment is financed by real loan $L_{i,t}$ at the bank

lending rate, R_t^L and real retained earning, $E_{i,t}$.

$$I_t = L_{i,t}^\omega E_{i,t}^{1-\omega}$$

We also assume that the continuum of firms incur a Rotemberg-style cost, when

they change prices. Rotemberg (1982) modeled the sluggish adjustment of prices by as-

suming that firms faced quadratic costs of making price changes. The Rotemberg model

assumes that all firms could adjust their price each period, but because of the adjustment

costs, they would only close partially any gap between their current price and the optimal

price. Here, we model these quadratic costs to adjust prices using the example given by

Ireland (2004). Such a cost is given by $\frac{\psi}{2}(\frac{P_{i,t}}{P_{i,t-1}} - 1)Y_t$. Firms pay dividends to share-holders

at the end of each period. In period t, firm i would have dividends $D_{i,t}$ as follows:

$$D_{i,t} = \frac{P_{i,t}Y_{i,t}}{P_t} - \frac{W_t N_t}{P_t} - \frac{R_{t-1}^L L_{i,t-1}}{\pi_t} - E_{i,t} - \frac{\psi}{2}(\frac{P_{i,t}}{P_{i,t-1}} - 1)Y_t$$

where $P_{i,t}Y_{i,t}$ is the real income from selling differentiated good $Y_{i,t}$; $\frac{W_t N_t}{P_t}$ is the

real labor cost; $\frac{R_t^L L_{i,t}}{P_t}$ is the real cost of loans $L_{i,t}$ and the bank lending rate, R_t^L. $E_{i,t}$ is

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[10]This results from the intratemporal decision of the households and from $C_t = Y_t$.

the real equity saved from revenue for investment production.

Firms maximize the expected present value of discounted dividends. Formally,

$$max \quad \sum_{k=0}^{\infty} E_t(\chi_{t,t+k}(D_{i,t+k}))$$

subject to the investment constraint and the sequence of demand constraints

$$Y_{i,t+k} = (\frac{P_{i,t+k}}{P_{t+k}})^{-\varepsilon} Y_{t+k}$$

for k=0, 1, 2...

where $\chi_{t,t+k} \equiv \beta^k (\frac{C_{t+k}}{C_t})^{-\sigma} \frac{P_t}{P_{t+k}}$ is the stochastic discount factor between periods t
and t+k.

3.2.3 Financial Intermediaries

Here, we partially follow the framework proposed by Ida (2011). Domestic financial
intermediaries or banks provide deposit services to domestic households. If a household
deposits an amount of J_t in period t, it receives a deposit of $R_t^J J_t$ at the end of the period.
The intermediaries receive deposits from households, and lend the funds to domestic firms.
Therefore, banks reallocate funds from the representative households to firms. We also
incorporate a financial shock in the banking sector. This financial market disturbance is
given by f_t.

Financial intermediaries face the following profit maximization problem:

$$\Pi_t(B) = E_t \chi_{t+1}[R_t^L L_t - R_t^J J_t] - e^{f_t} L_t$$

subject to a balance sheet constraint:

$$L_t = J_t.$$

This suggests that the loans that banks make to the firms, L_t are equal to the deposits they receive from households. χ_{t+1} is the stochastic discount factor, derived from the consumers optimization problem. The first order condition for the banks' optimization problem is therefore:

$$R_t^L - R_t^J = e^{f_t} E_t[R_{t+1}^e]$$

Here, we define the credit spread is as the difference between the lending interest rate R_t^L and the time deposit (or savings) interest rate R_t^J. In the presence of a financial shock, the credit spread would increase. The credit spread also dependent equity return which is the inverse of the stochastic discount factor.

3.2.4   Equilibrium

Our model is characterized by four markets: the bonds market, the equity market, the goods market and the labor market. The equilibrium in these four markets is given as follows:

In the bonds market, the net supply of bonds is equal to zero, i.e.

$$B_t = 0$$

In the equity market, the total amount of issued shares by the firms is normalized to one,

$$\int S_t(i) = 1$$

Also, the total real dividends and the aggregate stock price index are defined by aggregating over a continuum of firms as

$$D_t = \int_0^1 D_t(i)di$$

and

$$P_t^s = \int_0^1 P_t^s(i)di$$

On the aggregate demand side, we have market clearing conditions that hold in equilibrium along with the euler equations mentioned in the previous section. The market clearing in the goods market requires

$$Y_t(i) = C_t(i) + I_t(i)$$

$\forall i \in [0,1]$ and all t. Aggregate output is defined as $Y_t \equiv \left(\int_0^1 Y_t(i)^{1-\frac{1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}}$ and thus it follows that

$$C_t + I_t = Y_t$$

must hold $\forall t$ and

$$P_t Y_t = W_t N_t + P_t D_t$$

Also, the labor market clearing condition requires,

$$N_t = \int_0^1 N_t(i)di$$

3.2.5   Monetary Policy block

The central bank is assumed to set its nominal interest rate according to a Taylor rule, Taylor (1993). This rule suggests that interest rates are set in response to changes in

inflation and output gap.

$$r_t = (1 + \phi_\pi)\pi_t + \phi_y y_t + \phi_{spr}(Spread) + mp_t \tag{3.8}$$

The parameters ϕ_π, ϕ_y and ϕ_{spr} are coefficients on inflation, output gap and credit spread respectively. The monetary policy shock is given by mp_t. The credit spread is calculated as the difference between the bank lending rate and the federal funds rate.[11]

We assume that monetary policy follows an AR(1) process with persistence ρ_{mp}:

$$mp_t = \rho_{mp} mp_{t-1} + \varepsilon_{mp} \tag{3.9}$$

3.3 Estimation

In this section, we describe the estimation procedure and data, the calibrated parameters and our prior distribution of parameters.

3.3.1 Estimation procedure and data

As in An and Schorfheide (2007), the model presented in the previous section is estimated with Bayesian techniques[12] using six macroeconomic quarterly US time series as observable variables: the log of real GDP (detrended), equity return (detrended) , log difference of CPI, the federal funds rate, the log of real personal consumption expenditures (detrended) and the prime bank loan rate[13].

The vector Φ contains the parameters that will be estimated in our model:

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[11]Empirically, the three-month savings rate and the effective Federal funds rate are nearly perfectly correlated. Therefore, credit spread, the difference between the prime lending rate and the savings rate, has similar properties to the spread between the prime lending rate and the effective Fed-fund rate. Cúrdia and Woodford (2009) model the three-month savings rate to be identical to the effective Fed-funds rate.

[12]We do not opt to estimate our model using maximum likelihood techniques because such computation hardly converges to a global maximum.

[13]Both the federal funds rate and the prime bank loan rate are taken in levels.

$$\Phi = [\phi_\pi, \phi_y, \phi_{spr}, \rho_{ep}, \rho_{infl}, \rho_{mp}, \rho_f, \rho_{in}, \rho_a, \sigma_{ep}, \sigma_{infl}, \sigma_{mp}, \sigma_f, \sigma_{in}, \sigma_a]$$

We use quarterly data starting from 1959Q1 to 2012Q2 on real GDP, the CPI, the federal funds rate, real personal consumption expenditures, equity return and prime bank loan rate. The output gap y_t is computed by taking the difference between the log of the real GDP from the potential real GDP. We use a similar method for real personal consumption expenditures. The equity return is detrended using the Hodrick-Prescott filter[14]. Inflation, π_t, is computed as the annualized quarterly change in CPI. The nominal interest rate or the policy rate of the central bank denoted by r_t is taken directly as the federal funds rate in levels and so is the prime bank loan rate, r_t^L. The equity return is the Fama/French historical benchmark returns[15] The data is obtained from the FRED[16].

We use empirical definitions of these six time series for our estimation. These do not correspond to the theoretical definitions of deviations of the variable from it's steady state. However, we want to focus on more data-driven results and thus use the empirical definitions. A plot of the credit spread vs. the federal funds rate between 1983 and 2012 is presented in figure C.1. It suggests that in some time periods, the credit spread that is the difference between the prime bank loan rate and the savings rate and the federal funds rate which is the policy rate move in opposite directions. This pattern seems to be apparent in the recent financial crisis. The correlation between the credit spread and the policy rate is -0.7.

We also consider two sub-samples to see a shift if any in monetary policy[17].

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[14]The series are detrended using a smoothing parameter of 1600.

[15]The Kenneth R. French library gives the excess return on the market, as the value-weighted return on all NYSE, AMEX, and NASDAQ stocks (from CRSP) minus the one-month Treasury bill rate (from Ibbotson Associates).

[16]Federal Reserve Economic Data (FRED) for all series except the equity return which is taken from the Kenneth. R French - Data library

[17]Some authors have found evidence in favor of a monetary policy shift at the beginning of 1980's, see

The first sub-sample ranges from 1959Q1-1979Q1 and the second sub-sample ranges from 1983Q1-2007Q3. The model is estimated using Bayesian techniques to fit the six time series and the structural parameters of our model. First, we estimate the mode of the posterior distribution by maximizing the log posterior function, which combines the prior information on the parameters with the likelihood of the data. Second, using the Metropolis-Hastings algorithm we generate draws from the posterior distribution. At each iteration, the likelihood is evaluated using the Kalman filter[18]. We consider 300,000 draws, discarding 20% as initial burn in. The scale used for the jumping distribution is set to a value consistent with an acceptance rate in the neighborhood of 25% to ensure that we identify also the tails of the distribution correctly.

3.3.2 Calibrated parameters

There are few parameters that are fixed prior to our estimation. We follow baseline calibration as in Galí (2008). The discount factor β is fixed at 0.99. The choice of 0.99 corresponds to the long-run annual interest rate of 4%. Also, the coefficient of relative risk aversion, σ and the Frisch elasticity of labor supply is fixed to be one, corresponding to log utility. In line with most of the business cycle literature, we calibrate the proportion of capital income in production function α and Elasticity of substitution across differentiated goods, ε to be 1/3 and 6, respectively. The quarterly depreciation rate δ is calibrated as 2.5 percent which corresponds to the 10 percent annual depreciation rate. As in Woodford (2003), the model with the Rotermberg-style cost and with capital accumulation, $\psi = 30$, which gives the benchmark model the cost of price rigidity around 0.1%. The steady state value of λ, which can be interpreted as the wage markup in the labor market is calibrated

Clarida et al. (2000), Boivin and Giannoni (2006).

[18]All estimations are done using Dynare. For more information on its implementation and usage, see Adjemian et al. (2011).

to be 5. Following Ida (2011), we calibrate the steady state ratios of consumption to output and investment to output to be 0.5 and 0.15, respectively. The proportion of investment financed by loans is calibrated to be 0.5. This value is only assumed since no prior estimate can be found in the literature. Also, the K/Y ratio is calibrated to be 3 for the US. For the impulse response functions, we calibrate the coefficient on inflation and output gap in the Taylor rule to be 1.5 and 0.5 respectively.

3.3.3 Prior distribution of parameters

Following standard conventions, we calibrate beta distributions for parameters that fall between zero and one, inverted gamma distributions for parameters that need to be constrained greater than zero and normal distributions in other cases.

These priors are similar to the ones specified by Smets and Wouters (2007). The standard errors of the innovations are assumed to follow an inverse-gamma distribution with a mean of 0.01 and two degrees of freedom. The latter ensures that that these parameters have positive support. The persistence of the AR(1) processes are assumed to follow a beta distribution with mean 0.5 and standard deviation 0.25.

The parameters that describe monetary policy are based on the standard Taylor rule. We assume that the reaction of the nominal interest rate to inflation and output gap is described by a gamma distribution with mean 0.5. The reaction of the nominal interest rate to the credit spread is assumed to follow a normal distribution with a mean zero and a standard deviation of 0.25. This parameter is of particular interest in our study because it determines the systematic response of monetary policy to the fluctuations to the credit spread.

3.4 Empirical Results

Parameter	Decription	Prior			Posterior		
		Law	Mean	SD	Mean	5 percent	90 percent
ϕ_π	Fed's resp. to inf.	Gamma	0.5	0.25	0.59	0.5	0.69
ϕ_y	Fed's resp. to o/p gap	Gamma	0.5	0.25	0.45	0.34	0.56
ϕ_{spr}	Fed's resp. spread	Normal	0	0.25	-0.07	-0.52	0.38
ρ_{ep}	AR coeff., equity prem.	Beta	0.5	0.2	0.41	0.33	0.49
ρ_{infl}	AR coeff., cost push	Beta	0.5	0.2	0.94	0.92	0.96
ρ_{mp}	AR coeff, MP	Beta	0.5	0.2	0.4	0.30	0.50
ρ_f	AR coeff., financial	Beta	0.5	0.2	0.42	0.26	0.58
ρ_{in}	AR coeff., invest.	Beta	0.5	0.2	0.75	0.60	0.90
ρ_a	AR coeff., tech. shock	Beta	0.5	0.2	0.55	0.45	0.65
σ_{ep}	SE, equity prem.	InvGamma	0.01	2	0.09	0.07	0.11
σ_{infl}	SE, cost push	InvGamma	0.01	2	0.01	0.00	0.03
σ_{mp}	SE, MP	InvGamma	0.01	2	0.03	0.01	0.05
σ_f	SE, financial	InvGamma	0.01	2	0.10	0.05	0.15
σ_{in}	SE, invest.	InvGamma	0.01	2	0.02	0.01	0.03
σ_a	SE, tech shock	InvGamma	0.01	2	0.01	0.00	0.02
Log marginal likelihood = 3274.6							

Table 3.1: Estimation results for model (Benchmark): Full sample, 1959-2012

Table 3.1 presents the posterior estimates for our benchmark model as summarized by the log linearized representation of the model given in the Appendix C between 1959 and 2012. It presents the posterior mean and the 5% and 90% confidence percentiles of the posterior distribution of the parameters obtained by the Metropolis-Hastings algorithm. For the monetary policy rule, our model assumes that the Federal Reserve only responds to inflation, output gap and the credit spread. Parameters $(1 + \phi_\pi)$, ϕ_y and ϕ_{spr} determine the reaction of the Federal Reserve to inflation, output gap and credit spread. We find that our model estimates a significant response of the Fed to inflation and output gap. The posterior mean of $(1 + \phi_\pi)$ is about 1.59 with a Bayesian posterior interval of [1.50, 1.6] and the posterior mean of ϕ_y is about 0.45 with a Bayesian posterior interval of [0.34, 0.56]. The estimate of the reaction of the Fed to inflation is pretty close to the value estimated by Smets and Wouters (2007) and also suggests that the reaction of the Fed to inflation

followed the Taylor principle. The Taylor principle is the proposition that central banks can stabilize the macroeconomy by raising their interest rate instrument more than one-for-one in response to higher inflation[19]. However, the response of policy to output gap seems to be strong in our model as compared to the estimates of Smets and Wouters (2007). This is probably because in the reaction function of the central bank they include two responses to output. The first being the response to output gap and the second being the response to the changes in output gap. However, they do find a strong response of policy to the changes in output gap. Since, we don't allow for such a specification for the monetary policy rule, our estimate of ϕ_y could probably be capturing both, the response of output gap and changes in output gap. In terms of the response of the Fed to credit spreads over the full sample, we find that the nominal interest rate or the policy rate decreases as the credit spread increases. However, the response observed is very small - ϕ_{spr} has a posterior mean of -0.07 but lies in the broad Bayesian posterior interval of [-0.52, 0.38].

There are a few observations can be made with respect to our estimated responses for the exogenous shock variables. Overall, the data are very informative regarding the stochastic processes for these exogenous disturbances. Most shocks are not highly persistent as observed from AR(1) coefficient with the exception of the cost-push shock. However, the persistence of the monetary policy shock is much lower at around 0.5. Also, most shocks have a low standard deviation.

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[19]In the model, this suggests that the response of the Federal reserve to inflation given by $(1 + \phi_\pi) > 1$.

Parameter	Decription	Prior			Posterior		
		Law	Mean	SD	Mean	5 percent	90 percent
ϕ_π	Fed's resp. to inf.	Gamma	0.5	0.25	0.55	0.50	0.60
ϕ_y	Fed's resp. to o/p gap	Gamma	0.5	0.25	0.44	0.30	0.58
ϕ_{spr}	Fed's resp. spread	Normal	0	0.25	-0.03	-0.18	0.12
ρ_{ep}	AR coeff., equity prem.	Beta	0.5	0.2	0.46	0.4	0.52
ρ_{infl}	AR coeff., cost push	Beta	0.5	0.2	0.50	0.30	0.70
ρ_{mp}	AR coeff, MP	Beta	0.5	0.2	0.61	0.45	0.77
ρ_f	AR coeff., financial	Beta	0.5	0.2	0.42	0.36	0.48
ρ_{in}	AR coeff., invest.	Beta	0.5	0.2	0.54	0.25	0.83
ρ_a	AR coeff., tech. shock	Beta	0.5	0.2	0.48	0.38	0.58
σ_{ep}	SE, equity prem.	InvGamma	0.01	2	0.08	0.04	0.12
σ_{infl}	SE, cost push	InvGamma	0.01	2	0.02	0.00	0.03
σ_{mp}	SE, MP	InvGamma	0.01	2	0.02	0.00	0.03
σ_f	SE, financial	InvGamma	0.01	2	0.08	0.03	0.13
σ_{in}	SE, invest.	InvGamma	0.01	2	0.04	0.02	0.06
σ_a	SE, tech shock	InvGamma	0.01	2	0.01	0.00	0.02
Log marginal likelihood = 1408.03							

Table 3.2: Estimation results for model: Sub sample, 1959-1979

Parameter	Decription	Prior			Posterior		
		Law	Mean	SD	Mean	5 percent	90 percent
ϕ_π	Fed's resp. to inf.	Gamma	0.5	0.25	1.14	1.10	1.18
ϕ_y	Fed's resp. to o/p gap	Gamma	0.5	0.25	0.18	0.14	0.22
ϕ_{spr}	Fed's resp. spread	Normal	0	0.25	-0.80	-0.70	-0.90
ρ_{ep}	AR coeff., equity prem.	Beta	0.5	0.2	0.37	0.24	0.50
ρ_{infl}	AR coeff., cost push	Beta	0.5	0.2	0.65	0.56	0.74
ρ_{mp}	AR coeff, MP	Beta	0.5	0.2	0.31	0.28	0.34
ρ_f	AR coeff., financial	Beta	0.5	0.2	0.38	0.26	0.50
ρ_{in}	AR coeff., invest.	Beta	0.5	0.2	0.93	0.91	0.95
ρ_a	AR coeff., tech. shock	Beta	0.5	0.2	0.61	0.50	0.72
σ_{ep}	SE, equity prem.	InvGamma	0.01	2	0.08	0.04	0.12
σ_{infl}	SE, cost push	InvGamma	0.01	2	0.01	0.00	0.02
σ_{mp}	SE, MP	InvGamma	0.01	2	0.02	0.01	0.03
σ_f	SE, financial	InvGamma	0.01	2	0.09	0.06	0.12
σ_{in}	SE, invest.	InvGamma	0.01	2	0.01	0.00	0.02
σ_a	SE, tech shock	InvGamma	0.01	2	0.01	0.00	0.02
Log marginal likelihood = 1293.3							

Table 3.3: Estimation results for model: Sub sample, 1983-2007

In our next exercise, we consider two sub-samples. The first sub-sample is the

Great Inflation period from 1959 to 1979 and the second sub-sample is the Great Moderation

period from 1983-2007. We treat this break at 1983 as exogenous because several authors have documented the reduction of variability of inflation and output in the United States since the beginning of the 1980s[20]. Our estimates for these sub-samples are reported in Table 3.2 and Table 3.3, respectively.

First, considering the Great Inflation period, we find that the response of the Fed to inflation has been very strong with the response coefficient $(1 + \phi_\pi) = 1.55$. Also, the response coefficients for output gap are highly significant taking a value of $\phi_y = 0.44$. However, the response of the Fed to credit spreads is very small, $\phi_{spr} = -0.03$. Comparing these results to the Great Moderation period, we find that the response of the Fed to inflation is much stronger with $(1 + \phi_\pi) = 2.14$. The response of the Fed to the output gap is lower in the great moderation period. We do find a high response of the Fed to credit spreads. The coefficient, ϕ_{spr} is -0.8 and lies in the Bayesian posterior interval of [-0.7, -0.9]. This suggests that the Fed responds aggressively to the movements in credit spreads. Basically, we can interpret a negative coefficient on the credit spread in the following way - a rise in the credit spreads, say during periods financial stress induces the Fed to lower their policy rate in order to combat the financial shock. We can evaluate the importance of including the credit spread in the Taylor rule by comparing the log-marginal likelihood of this model to the case with no credit spread. In order to see if the Taylor rule with the credit spread improves the model fit, we repeated the estimation exercise for the Great Moderation period without the credit spread in the Taylor rule and found that including the credit spread in the monetary policy rule, increases the log marginal likelihood by 28 points. We also considered our estimation exercises from 1959-1982 and 1983-2012. For the period 1959-1982 we find that there is a substantial increase in the negative response

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[20]See, for example, McConnell and Perez-Quiros (2000) and Blanchard and Simon (2001)

of the Fed to credit spreads, $\phi_{spr} = -1.12$. For the period 1983-2012, there is only a slight increase in the repsonse of the Fed to credit spreads, $\phi_{spr} = -0.83$.

3.5   Impulse Responses

In this section we discuss two questions. First, how does a financial shock in the economy affect our macro variables of interest. Second, whether the transmission of monetary policy is different under an economy with or without financial intermediaries.

The results of the first exercise are depicted in Figure C.2. The intuition is as follows. The financial shock decreases the supply of loans that is caused by an increase in the bank loan rate. In response to a financial shock, the central bank decreases it's policy rate. A decrease in the policy rate along with an increase in the bank loan rate are responsible for an increase in the credit spread. An increase in the credit spread causes a reduction in investment which decreases output. Lower output results in both, lower consumption and lower inflation. Another interesting result here is to see how a financial shock that increases the credit spread also increases the equity return. Since firms finance their investment using heterogeneous funds: bank loans and retained earnings, a decrease in the bank loans caused by an increase in the bank loan rate, would induce firms to finance their investments out of retained earnings rather than bank loans. This results in an increase in the equity return because of an increase in the marginal product of capital.

The results of our second exercise are depicted in Figure C.3 and C.4. Here we compare the effect of a monetary policy shock in a model with and without financial in-termediaries on output, consumption, inflation, investment, equity return and the policy rate. In response to a positive monetary policy shock, we find that a model with financial intermediaries tends to increase the fluctuations in consumption, inflation, equity returns

relative to a model without financial intermediaries. The effect of a monetary policy shock is also stronger on the policy rate in the model with financial intermediaries. The effect of output and investment is similar in both models. Thus, an economy with financial interme- diaries observes higher volatility in most macro variables in response to a monetary policy shock. An increase in the policy rate causes output, consumption, inflation, investment and equity return to fall.

3.6   Conclusion

This paper contributes to the literature on credit spreads and monetary policy. By extending the standard New Keynesian model to include the stock market and financial intermediaries, we answer a couple of important questions. First, to what extent has the Fed responded to credit spreads and whether this policy has changed between the Great Inflation and the Great Moderation period. We find that relative to the Great Inflation period, the Fed has responded very aggressively to increases in credit spreads by lowering the policy rates in order to stimulate the economy. Second, we ask how does a financial shock affect the macro variables in the economy. We find that due to the increase in financial stress, banks charge higher rates on their loans and at the same time monetary policy is accommodative. Both these factors affect the credit spread that rises and causes investment and output to fall. Consumption and inflation are lower as a result. Lastly, we compare an economy with financial intermediaries to an economy without financial intermediaries in the presence of a monetary policy shock. We find that the presence of financial intermediaries results in a higher volatility of most macro variables in our set up.

Appendix C

Appendix

C.1 Consumer's Optimization Problem

$$max \quad E_t \sum_{k=0}^{\infty} \beta^k U(C_{t+k}, N_{t+k})$$

subject to

$$P_t C_t + Q_t B_t + P_t P_t^s S_t + J_t + T_t \leq B_{t-1} + W_t N_t + P_t P_t^s S_{t-1} + P_t D_t S_{t-1} + \Pi(B) + R_t^J J_{t-1} \quad \text{(C.1)}$$

Let λ_t be the Lagrange multiplier on the budget constraint. We obtain the first-order conditions with respect to C_t, N_t, B_t, S_t and J_t:

$$U_{C,t} + P_t \lambda_t = 0 \qquad \text{(C.2)}$$

$$U_{N,t} + W_t \lambda_t = 0 \qquad \text{(C.3)}$$

$$\lambda_t Q_t - \beta E_t \lambda_{t+1} = 0 \qquad \text{(C.4)}$$

$$\lambda_t P_t P_t^s - \beta E_t \lambda_{t+1}(P_{t+1} P_{t+1}^s + P_{t+1} D_{t+1}) = 0 \qquad \text{(C.5)}$$

$$\lambda_t - \beta R_t^j E_t \lambda_{t+1} = 0 \qquad \text{(C.6)}$$

Equation (C.2) and (C.4) give the Euler equation. Equation (C.3) and (C.5) determine the labor supply and the real return on the financial asset. The optimality conditions implied by the maximization of (3.1) with respect to (C.1) are given by

$$-\frac{U_{N,t}}{U_{C,t}} = \frac{W_t}{P_t} \tag{C.7}$$

$$Q_t = \beta E_t[\frac{U_{C,t+1}}{U_{C,t}}\frac{P_t}{P_{t+1}}] \tag{C.8}$$

for $t = 0, 1, 2....$Assuming the period utility takes the form as described by (3.3), we can write (C.7) and (C.8) as

$$\frac{W_t}{P_t} = C_t^\sigma N_t^\phi$$

The log-linear version of this intra temporal optimality condition[1] can be written as

$$w_t - p_t = \sigma c_t + \phi n_t$$

The euler equation can be written as

$$Q_t = \beta E_t \left\{ \left(\frac{C_{t+1}}{C_t}\right)^{-\sigma} \frac{P_t}{P_{t+1}} \right\}$$

Also, from (C.6) we have, $1/R_t^j = Q_t$

Taking logs on both sides, yields

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[1]The lowercase variables denote the logs of the respective variables from the steady state(i.e. $x_t \equiv log(X_t/X)$

$$log(Q_t) = log(\beta) - \sigma E_t[\sigma(c_{t+1} - c_t) + p_t - p_{t+1}]$$

$$-i_t = -\rho - \sigma E_t(\Delta c_{t+1}) - E_t \pi_{t+1}$$

$$c_t = E_t c_{t+1} - \frac{1}{\sigma}(i_t - E_t \pi_{t+1} - \rho)$$

where $i_t \equiv -log(Q_t)$ is the short term nominal rate and $\rho \equiv -log(\beta)$ is the discount rate. Equation (C.9) is the log-linearized euler equation.

Equation (C.5) yields

$$1 = E_t[\beta \frac{U_{C,t+1}}{U_{C,t}} \frac{P_{t+1}^s + D_{t+1}}{P_t^s}] \tag{C.9}$$

The above equation can be re-written as:

$$\frac{1}{E_t \chi_{t+1}} = E_t[R_{t+1}^e] \tag{C.10}$$

where $E_t[R_{t+1}^e]$ is the equity return and is equal to $E_t[\frac{P_{t+1}^s + D_{t+1}}{P_t^s}]$

C.2 Firm's problem

$$E_t \sum_{k=0}^{\infty} \chi_{t+k,t} \frac{P_{i,t} Y_{i,t}}{P_t} - \frac{W_t N_t}{P_t} - \frac{R_{t-1}^L L_{i,t-1}}{\pi_t} - E_{i,t} - \frac{\psi}{2}(\frac{P_{i,t}}{P_{i,t-1}} - 1)Y_t$$

subject to

$$A_t K_t(i)^\alpha N_t(i)^{1-\alpha} - (\frac{P_{i,t}}{P_t})^{-\varepsilon} Y_t$$

and

$$K_{t+1} = (1-\delta)K_t + I_t$$

Defining $\lambda_{i,t}$ as the Lagrangian multiplier associated with intermediate firm is production function, and $\mu_{i,t}$ as the Lagrangian multiplier associated with capital accumulation in period t. The firm would set it's price $P_{i,t}$. The first order conditions for the firms optimization problem with respect to $N_t, L_{i,t}, E_{i,t}, K_{i,t+1}$ and $P_{i,t}$ are:

$$\frac{W_t}{P_t} = \lambda_{i,t}(1-\alpha)\frac{Y_{i,t}}{N_t(i)}$$

$$E_t[\chi_{t+1}\frac{R_t^L}{\pi_{t+1}}] = \omega\mu_{i,t}\frac{I_{i,t}}{L_{i,t}}$$

$$(1-\omega)\lambda_{i,t}\frac{I_{i,t}}{E_{i,t}} = 1$$

$$\chi_{t-1}[\alpha\lambda_{i,t+1}\frac{Y_{i,t}}{K_{i,t}} + (1-\delta)\mu_{i,t+1}] - \mu_{i,t} = 0$$

$$\frac{Y_{i,t}}{P_t} - \psi\frac{Y_t}{P_{i,t-1}}(\frac{P_{i,t}}{P_{i,t-1}} - 1) + \lambda_{i,t}[\varepsilon(\frac{P_{i,t}}{P_t})^{-\varepsilon-1}\frac{Y_t}{P_t}] + E_t\chi_{t+1}[\frac{\psi Y_{t+1}P_{i,t+1}}{2(P_{i,t})^2}]$$

In a symmetric equilibrium, all i firms are identical and will set the same price. The conditions are re-written without the subscript in the next section.

C.3 The complete model

Consumers:

$$\frac{W_t}{P_t} = C_t^\sigma N_t^\phi \tag{C.11}$$

$$Q_t = \beta E_t \left\{ \left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} \frac{P_t}{P_{t+1}} \right\} \tag{C.12}$$

$$\frac{1}{E_t \chi_{t+1}} = E_t[R^e_{t+1}] \tag{C.13}$$

Firms:

$$\frac{W_t}{P_t} = \lambda_t(1-\alpha)\frac{Y_t}{N_t} \tag{C.14}$$

$$E_t[\chi_{t+1}\frac{R^L_t}{\pi_{t+1}}] = \omega\mu_t\frac{I_t}{L_t} \tag{C.15}$$

$$(1-\omega)\lambda_t\frac{I_t}{E_t} = 1 \tag{C.16}$$

$$\chi_{t-1}[\alpha\lambda_{t+1}\frac{Y_t}{K_t} + (1-\delta)\mu_{t+1}] - \mu_t = 0 \tag{C.17}$$

$$[\lambda_t - \frac{\varepsilon-1}{\varepsilon}] = \frac{\psi}{\varepsilon}E_t[(\pi_t-1)\pi_t - \beta(\frac{C_t}{C_{t+1}})^{-\sigma}\frac{Y_{t+1}}{Y_t}(\pi_{t+1}-1)\pi_{t+1}] \tag{C.18}$$

$$A_t K_t^\alpha N_t^{1-\alpha} = Y_t \tag{C.19}$$

$$K_{t+1} = (1-\delta)K_t + I_t \tag{C.20}$$

$$I_t = L_t^\omega E_t^{1-\omega} \tag{C.21}$$

Financial Intermediary:

$$r_t^L - r_t^J = E_t[r_{t+1}^e] + f_t \tag{C.22}$$

Monetary Policy:

$$i_t = \phi_\pi \pi_t + \phi_y y_t + \phi_{spread}(r_t^L - r_t^J) + mp_t \tag{C.23}$$

$$Y_t = C_t + I_t \tag{C.24}$$

C.4 Log-linearized model

Consumers:

$$w_t = \sigma c_t + \phi n_t \tag{C.25}$$

$$c_t = E_t c_{t+1} - \sigma^{-1}[r_t - E_t \pi_{t+1}] \tag{C.26}$$

where $i_t = -logQ_t$

$$E_t r_{t+1}^e = -E_t \chi_{t+1} + ep_t \tag{C.27}$$

Firms:

$$w_t = \lambda_t + y_t - n_t \tag{C.28}$$

$$E_t \chi_{t+1} + r_t^L - E_t \pi_{t+1} = \mu_t + i_t - l_t \tag{C.29}$$

$$\chi_{t-1} = \mu_t - \frac{\alpha\lambda\frac{Y}{K}}{(.)}(\lambda_{t+1} + y_t - k_t) - \frac{(1-\delta)\mu}{(.)}\mu_{t+1} \tag{C.30}$$

where $(.) = (\alpha\lambda\frac{Y}{K} + (1-\delta)\mu)$

$$\pi_t = \beta E_t \pi_{t+1} + \frac{\varepsilon - 1}{\psi}\lambda_t \tag{C.31}$$

$$\lambda_t + i_t = e_t \tag{C.32}$$

$$y_t = a_t + \alpha k_t + (1-\alpha)n_t \tag{C.33}$$

$$k_{t+1} = (1-\delta)k_t + i_t \tag{C.34}$$

$$i_t = \omega l_t + (1-\omega)e_t \tag{C.35}$$

$$r_t^L - r_t^J = e^{v_t} E_t[r_{t+1}^e] \tag{C.36}$$

Monetary Policy:

$$r_t = \phi_\pi \pi_t + \phi_y y_t + \phi_{spread}(r_t^L - r_t^J) + mp_t \tag{C.37}$$

$$y_t = \frac{C}{Y}c_t + \frac{I}{Y}i_t \tag{C.38}$$

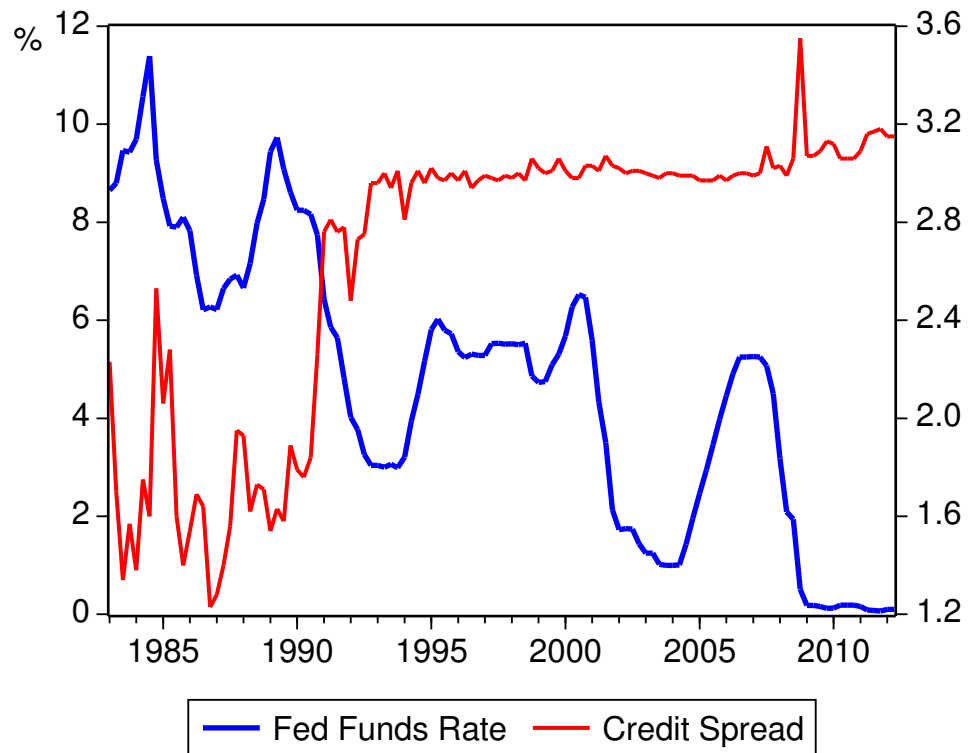$$E_t\chi_{t+1} = -\sigma(E_t c_{t+1} - c_t) - E_t\pi_{t+1} \tag{C.39}$$

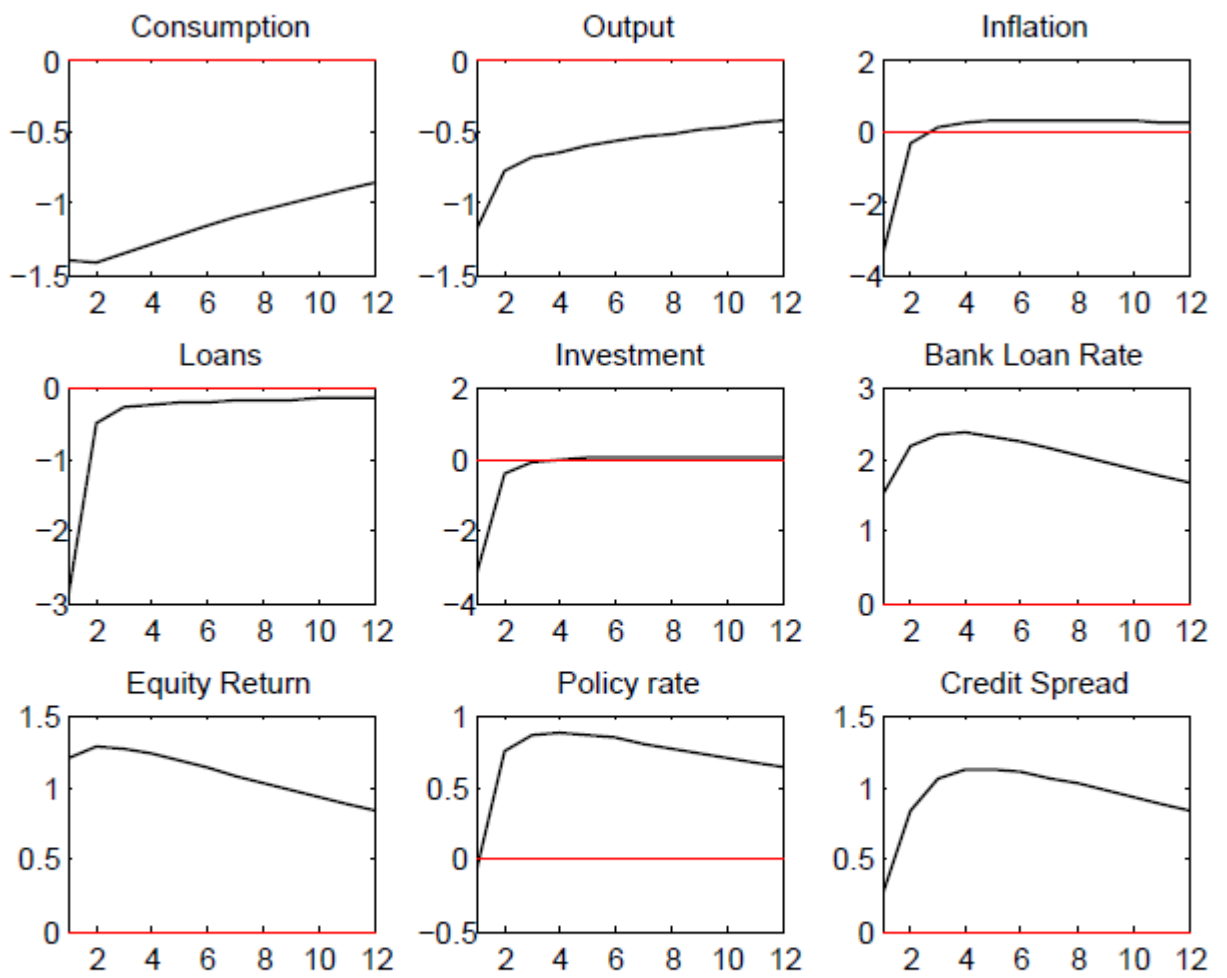Figure C.1: Credit Spread vs. Federal Funds Rate

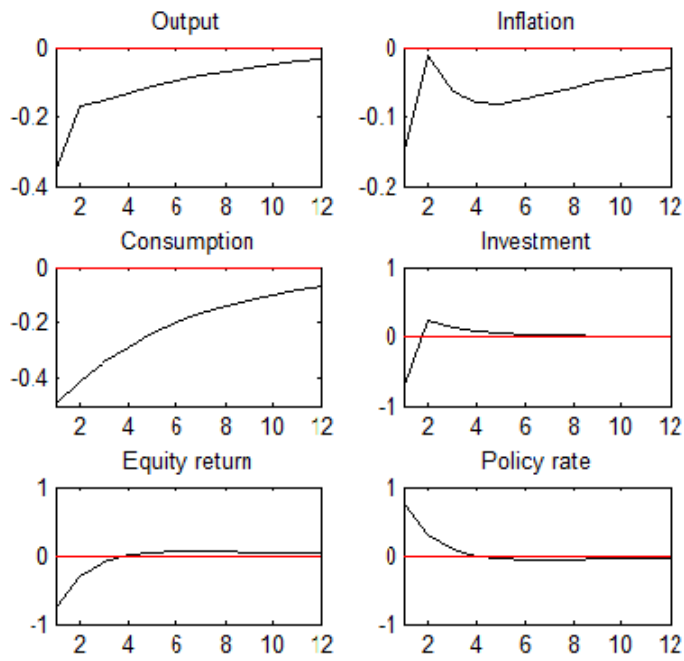Figure C.2: Impulse Responses to a financial shock

Figure C.3: Impulse Responses to a monetary policy shock without financial intermediaries
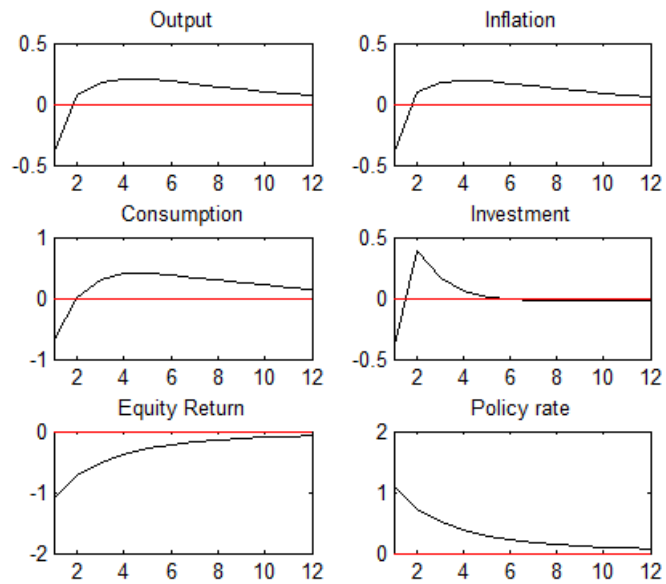

Figure C.4: Impulse Responses to a monetary policy shock with financial intermediaries

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