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THE EFFECT OF CONVENTIONAL AND UNCONVENTIONAL MONETARY POLICY RULES ON INFLATION EXPECTATIONS: THEORY AND EVIDENCE

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ABSTRACT

This paper has three parts. First, I provide a theoretical framework to explain how rational expectations models, where the central bank follows a conventional monetary policy rule, can be used to understand the history of interest rates and inflation in the period between 1951 and the Great Recession of 2008. Second, I use the framework developed in the first part of the paper to illustrate how the purchase of assets other than treasuries, for example, mortgage backed securities and long bonds, can influence inflation expectations when the interest rate is zero. Third, I show that the beginning of unconventional monetary policy in 2008 coincided with a significant increase in inflation expectations. I extend existing models of monetary policy by adding explicit markets for financial securities. Using this extended framework, I show that the purchase of assets, other than short term treasury bills, has a differential impact on the prices of risky securities. Unconventional monetary policy is an important tool in a central bank's arsenal that can be used to help prevent deflation in the wake of a financial crisis.

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(I) Introduction

This paper has three parts. First, I provide a theoretical framework to explain how rational expectations models, where the central bank follows a monetary policy rule, can be used to understand the history of interest rates and inflation in the period between 1951 and the Great Recession of 2008. Interest rates were positive during this period and monetary policy worked through the purchase and sale of treasury bills on the open market. I will refer to this as *conventional monetary policy*.

Second, I use the framework developed in the first part of the paper to illustrate how the purchase of assets other than treasuries, for example, mortgage backed securities and long bonds, can influence expected inflation when the interest rate is zero. Once the interest rate has reached zero, conventional monetary policy is no longer effective, because the nominal rate cannot become negative. This situation is widely referred to as a *liquidity trap*. I will refer to a policy in which the Fed changes the composition of its balance sheet by purchasing assets other than three month treasuries as *unconventional monetary policy*.

The adoption of unconventional monetary policy by the Fed in the Autumn of 2008 is referred to in the popular press as QE1. In the third part of the paper, I show that the beginning of unconventional monetary policy in 2008 coincided with a significant increase in inflation expectations as measured by the price of inflation swaps in financial markets. I demonstrate that the beginning and end of Fed interventions in the market for mortgage backed securities coincided closely with the timing of changes in the direction of movements in stock market prices.

In Part 1 of the paper, I illustrate how rational expectations models can explain the observed behavior of expected and actual inflation.[2] Inflation and interest rates were lower and less volatile in the period from 1983-2008 than in the previous period from 1951 to 1979. Clarida et. al (1999) have argued that this improved performance was caused by a change in Fed operating procedure when Volcker took over as Chairman of the Fed in 1979. The model I develop here demonstrates, in a transparent way, how their argument depends on two important assumptions. First, that agents have rational expectations, and second, that the central bank follows a monetary policy rule.

[2] There is an active debate among different groups of economists over the effects of monetary policy on inflation and unemployment. I will have nothing to say here about the possible effects of conventional or unconventional monetary policy on real economic activity, a topic I have discussed elsewhere (Farmer 2013). I argue there, that monetary shocks may have permanent effects on unemployment because labor markets are incomplete. This assumption is distinct from both classical (Chari et. al. 2009) and new-Keynesian models (Clarida et. al. 1999) where business cycles are modeled as temporary fluctuations around a 'natural rate' of output.

My model is not a simple replication of Clarida et. al. By providing an explicit model of how the monetary policy rule influences the entire spectrum of asset prices, I am able to extend existing models, and to illustrate the importance of unconventional monetary policy, when the interest rate reaches its lower bound. I show that the purchase of assets, other than short term treasury bills, has a differential impact on the prices of risky securities, for example, mortgage backed securities or long-term bonds.

By buying or selling risky assets a central bank can signal its intention to operate a different monetary rule in future states, and thereby influence inflation and inflation expectations when the economy is in a liquidity trap.[3] In other words, unconventional monetary policy is an important tool in a central bank's arsenal that can be used to help prevent deflation in the wake of a financial crisis.

(II) Part 1: Conventional Monetary Policy in the Post-War Period

(i) The Great Moderation

During World War II, the Federal Reserve in the United States was committed to keep interest rates low to help the Treasury pay for the war.[4] This commitment ended in 1951, and from 1951 to 1979, the Fed followed a policy of raising the interest rate in response to increases in inflation or increases in growth and lowering it as inflation subsided or as the economy fell into recession. I will refer to the percentage by which the Fed raises the interest rate, in response to a one percent increase in inflation, as the Fed's inflation-reaction coefficient.

From 1951 through 1979, the Fed responded to inflation with a relatively low inflation-reaction coefficient. The result was a slow buildup of inflation, which went from 1% per year in 1953 to more than 13% in 1980, and a period of volatile and high inflation and volatile growth. At the same time, the unemployment rate increased from 3% in 1953 to 7.5% in 1981. The combination of high inflation and high unemployment was unprecedented in the U.S. and led to considerable

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[3] Although this paper has nothing to say about the effect of monetary policy on real economic activity, the framework I provide can be easily adapted to study that issue. Here, I close the model with the assumption that real GDP is determined by fundamentals. By making that assumption, I leave no room for monetary policy to change real GDP or to influence unemployment. An alternative way of closing the model would be with a *belief function* in a model with incomplete labor markets, as in Farmer (2013). In that environment, alternative monetary policy rules will have permanent effects on unemployment. A new-Keynesian way of closing a monetary model can be found in Cúrdia and Woodford (2010). Their work preserves the natural rate hypothesis, a property that is hard to defend in the wake of the 2008 financial crisis where unemployment rates in most western nations have remained persistently high for more than three years.

[4] The commitment ended when the Fed and the Treasury signed an agreement, the *Accord*. For an account of this period see the Federal Reserve Bank of Richmond *Economic Quarterly, Special Issue*, Winter (2001).

discontent. As a consequence, Paul Volcker was brought in as Chairman of the Federal Reserve Board and was tasked with bringing inflation under control.

Volcker followed a policy of strict control of the money supply, as opposed to control of the interest rate. This policy rapidly reduced inflation at the cost of a period of high interest rates and a big spike in unemployment. In 1983, Volcker returned to a policy of interest rate control, but the implementation of that policy changed. After 1983, the inflation-reaction coefficient increased; the Fed raised the short-rate by a larger percentage in response to inflation than it had done in the period from 1951 through 1979. The result was a period of remarkable stability in which inflation and unemployment fell, and inflation, growth, and unemployment all became less volatile. Because of increased stability in inflation, unemployment and GDP growth that occurred after 1983, this period has been called the *Great Moderation*.

In my view, the monetary policy rule that was followed from 1983 through 2006 was directly responsible for the Great Moderation.[5] Looking at the Great Moderation from the perspective of the economic crisis of 2008, it is tempting to argue that monetary theory failed. But although economists did not predict the crisis, it would be a mistake to jettison all that we learned from this period.

(ii) Rational expectations and stationarity

Rational expectations macroeconomic models are represented by stationary solutions to stochastic difference equations of the kind described in equations (1) and (2).

$$\mathrm{s}' = g(\mathrm{s}, \varepsilon'), \tag{1}$$

$$X = \phi(\mathrm{s}). \tag{2}$$

s is a vector of *state variables* in the current period, X is a set of variables of interest and a prime on a variable indicates that it occurs in the subsequent period. ε' is a random event that causes the state to change from s to s'.[6]

[5] This explanation was first advanced by Clarida et. al. (2000). It is not the only explanation that has been put forward to explain the Great Moderation. Competing narratives involve: good luck (Sims and Zha 2006) and changes in technology (McConnell-Perez-Quiros 2000).

[6] In more complicated models the state may include economic variables such as the capital stock or the distribution of wealth across households. This makes the equations more complicated but it does not alter the principle that economic systems are modeled with stationary stochastic equations like those described in (1) and (2).

Equation (1) tells us that the state evolves according to a rule, captured by the function $g(\cdot)$. Equation (2) tells us that the economic variables, *X*, depend on the state, captured by the function $\phi(s)$.

In principle, the variables, *X*, might be changing over time even if the state remains constant. By studying stationary solutions to stochastic difference equations, we are assuming this does not happen. Every time the economy enters state, *s*, we would expect to see the same values of all of the observable variables.

Stationarity and rational expectations go hand in hand. The theory of rational expectations tells us that the agents who populate our models should use the same probability measures to predict future inflation rates as the measures that describe the actual probabilities that inflation will take on any particular value. Stationarity is an important component of the theory because it implies that agents have a reasonable chance, through observation, to learn what these probabilities are in practice. Expectations are are built into the function $\phi(s')$, which represents the solution to a complete macroeconomic model.

(iii) Asset pricing and financial markets

Modern financial markets display a staggering degree of complexity and it is possible to make contingent trades on almost any conceivable set of future events. To make computations easier, theorists break the vast array of financial assets down into simpler units called Arrow securities, named after the economist Kenneth Arrow (Arrow 1964). An Arrow security is a promise to deliver one dollar in state, s', if and only if state, s', occurs. Financial economists have shown that every financial asset can be represented as a collection of Arrow securities.

The price of an Arrow security is described by a function, $Q(s, s')$, called the *pricing kernel*.[7] Financial economists employed by investment banks and hedge funds use this concept on a daily basis to decide how much an asset is worth.

For example, consider an asset that costs $q(s)$ today and pays a stream of dividends $\{d(s'), d(s''), \ldots\}$ in a sequence of future states $\{s', s'', \ldots\}$. It might be a share in a company that pays a dividend $d(s')$ or it might be a bond that pays a coupon, $d(s') = d$, in every state. The *asset pricing equation*, gives us a way of pricing this security,

$$q(s) = \sum_{s'} \{Q(s, s')[q(s') + d(s')]\}. \tag{3}$$

The left side of this expression is the price of the security today. The right side sums the payoffs of the security tomorrow over all possible subsequent states weighted by the pricing kernel.

[7] In more complicated models, the state next period may be represented by an interval [a,b] rather than by a single value. In that more general environment the first argument of the function $Q(\cdot,\cdot)$ is the current value of the state and the second argument is a *set* of values. A function like this, where the second argument is a set, is called a *kernel*.

Notice that the payoffs in each future state include any dividend that the security pays; this is the term $d(s')$, plus the value of reselling the security; this is the term $q(s')$.

(iv) Central Banks and financial markets

Central banks intervene in the financial markets by buying and selling securities. As an example, consider a one-dollar treasury bill that promises $(1+i)$ dollars next period. If we make the reasonable assumption that the U.S. government will not default on its promise, this security will payoff $(1+i)$ dollars *in every state*. In the notation of Equation (3), the resale price of the bond, $q(s')$, is equal to 1, and the coupon payment, $d(s')$, is equal to i.

To replicate the payoff of this bill using Arrow securities, a household would need to purchase a complete set of these securities. Applying the pricing Equation, (3), the interest rate, i, must be related to the prices of the Arrow securities by Equation (4),

$$1 = \sum_{s'} Q(s, s')(1+i). \tag{4}$$

Rearranging this expression we see that the gross interest rate, $(1+i)$, is the inverse of the sum of the Arrow security prices,

$$(1+i) = \frac{1}{\sum_{s'} Q(s, s')}. \tag{5}$$

By buying and selling securities on the open market, the Fed influences the pricing kernel. If the Fed raises the short rate, it will reduce the sum of all Arrow securities prices. If it lowers the short rate, the Fed will raise that sum. But how do those policy actions influence inflation and GDP? To answer that question, we must develop a theory of the value of money in each state. We need a theory of Q.

(v) What determines Q?

$Q(s, s')$ is the price at which a household or a firm can trade a dollar today in state, s, for a dollar tomorrow, in state, s'. It depends on the preferences of households, the endowments of labor and land, and the technology available for transforming goods today into goods tomorrow.

Modern macroeconomics makes strong simplifying assumptions which imply that $Q(s, s')$ is a function of three things: the inflation rate, the growth rate of real GDP, and the conditional probability that state, s', will occur given that state, s, occurred today.[8] I will represent the dependence of Q on inflation, π, and growth, Δy, by a function $f[\pi(s'), \Delta y(s')]$ where the properties of $f[\cdot]$ depend on assumptions about a complete macroeconomic model. Using this notation, we can write,

[8] To be more precise, $Q(s, s')$ depends on inflation and *consumption* growth. I ignore the distinction between GDP and consumption here, to keep the exposition simple. This simplification has a long history in the literature on monetary economics.

$$Q(s,s') = p_{s,s'} f[\pi(s'), \Delta \mathrm{y}(s')], \tag{6}$$

where, $p_{s,s'}$ is the conditional probability that state, s' will occur.

One commonly used model, the representative agent model, leads to the function,

$$f[\pi(s'), \Delta \mathrm{y}(s')] = \beta \frac{1}{\pi(s')} \frac{1}{\left(\Delta \mathrm{y}(s')\right)^{\rho}} \tag{7}$$

where ρ is a non-negative number that is high when households dislike taking risks and β is a number between 0 and 1 that describes impatience. In this essay, I will maintain the form of Equation (7), and I will examine its implications for the way we conduct monetary policy.

(vi) Monetary policy as a rule

Following the Accord in 1951, the Fed raised the interest rate in response to inflation or rapid output growth and lowered it when inflation receded or when the economy was falling into a recession. Macroeconomists represent this policy by a *reaction function*,

$$(1+i) = r[\pi(s), \Delta \mathrm{y}(s)], \tag{8}$$

where the notation $r[\pi(s), \Delta \mathrm{y}(s)]$ is shorthand for a function that describes how the central bank alters the interest rate in response to current inflation, $\pi(s)$, and current output growth, $\Delta \mathrm{y}(s)$.[9] What does the theory of rational expectations tell us about the inflation rate that would occur if the central bank were to set the interest rate using a policy reaction function like this?

Using equations (5) through (8), it follows that the inflation rate in each future state is linked to the interest rate in the current period by Equation (9),

$$\frac{1}{r[\pi(s), \Delta \mathrm{y}(s)]} = \sum_{s'} p_{s,s'} f[\pi(s'), \Delta \mathrm{y}(s')]. \tag{9}$$

This is a stochastic version of a familiar expression that appears in undergraduate economics textbooks, the Fisher Equation. To see this, suppose that there is only one state and no growth so that $\Delta \mathrm{y} = 1$. Using the connection between $(1+i)$ and Q from Equation (5) and the functional form $of\ f[\cdot]$, from Equation (7), we can write

$$\frac{\pi}{1+i} = \beta. \tag{10}$$

[9] The policy rule is often represented as a function of inflation and the difference of real GDP from target. This latter variable is called the *output gap*. I have substituted GDP growth for the output gap in this discussion since it simplifies the exposition of some key ideas without altering the substance of my argument.

The left-side of (10) is the inverse of the gross real interest rate and the right-side is the discount factor of the representative agent.

We can go further and illustrate how the Fisher equation and the central bank reaction function will, together, determine inflation. Replacing the interest rate in (10) with the monetary rule (8), leads to (11),

$$\frac{\pi}{r(\pi,1)} = \beta. \tag{11}$$

By picking the rule, $r(\pi, 1)$, the central bank can choose the steady state inflation rate as a function of the time preference parameter, β.

Monetary policy in a stationary stochastic environment, where GDP may fluctuate, works the same way as the one-state example; but now there is a different inflation rate and a different growth rate in each state. In the case when there are two states, Equation (9) becomes a system of two equations in four unknowns,

$$\begin{aligned} \frac{1}{r[\pi(a),\Delta \mathrm{y}(a)]} &= p_{a,a} f[\pi(a),\Delta \mathrm{y}(a)] + p_{a,b} f[\pi(b),\Delta \mathrm{y}(b)], \\ \frac{1}{r[\pi(b),\Delta \mathrm{y}(b)]} &= p_{b,a} f[\pi(a),\Delta \mathrm{y}(a)] + p_{b,b} f[\pi(b),\Delta \mathrm{y}(b)]. \end{aligned} \tag{12}$$

The unknowns are $\pi(a)$ and $\pi(b)$, the inflation rates in states, a, and b, and $\Delta y(a)$ and $\Delta y(b)$, the growth rates in these states.

When the fundamentals enter state a, the economy grows at rate $\Delta \mathrm{y}(a)$, and the inflation rate is equal to the $\pi(a)$. When the fundamentals enter state b, the economy grows at rate $\Delta \mathrm{y}(b)$ and the inflation rate is equal to π(b). To determine inflation in each state, we must break down monetary policy into its effects on inflation and its effects on growth. Since we have two equations and four unknowns we will need two more equations to determine all of the variables of interest.

(vii) A classical model of inflation and growth

The relative impact of monetary policy on output and employment is an important question. But it is separate from the theory of rational expectations that I will address here, and, in the interests of making my points in the simplest way, I will explain how monetary policy affects inflation in a classical model with flexible prices in which output growth is determined by the fundamentals of the economy.[10]

[10] Farmer (2012a,b) constructs a real model with incomplete labor markets and Farmer (2013) develops a monetary model with incomplete labor markets where a *belief function* substitutes for the new-Keynesian Philips curve. For a similar approach see Kocherlakota (2012). Farmer's (2013) model provides a better fit to the data than the new-Keynesian approach (Clarida et. al. 1999) because it is able to endogenously account for persistence in the

In the classical model, monetary policy has no impact on economic activity either in the short-run or in the long run. Economic growth may vary from one period to the next in response to fluctuations in the state, but there is nothing that the central bank can do to influence those fluctuations.

Using this assumption, I will set $s = \{a, b\}$ to represent the possibility that output growth may be high or low. We now have two new equations to supplement the system (12),

$$\begin{aligned} \Delta y(s) &= \Delta y_a, \\ \Delta y(s) &= \Delta y_b, \end{aligned} \tag{13}$$

where Δy_a and Δy_b are numbers that represent the growth rate that occurs in states a and b. Equations (12) and (13) together explain all four variables, $\pi(a), \pi(b), \Delta y(a)$ and $\Delta y(b)$.

Suppose that the central bank follows the policy rule

$$r[\pi(s), \Delta y(s)] = \bar{I}\pi(s)^{\eta}\Delta y(s)^{\phi}, \tag{14}$$

where $\bar{I}$ is the interest rate that would be chosen if inflation was zero, and η and ϕ are reaction coefficients. I will refer to $\bar{I}$ as the zero-inflation target.

Rules like this are called *Taylor Rules* after the economist John Taylor (Taylor 1993) who showed that they do a good job of explaining the behavior of actual monetary policy in the U.S. in the post-war period. The reaction coefficients have the interpretation that if inflation were to increase by 1%, the central bank would respond by increasing the interest rate by η% and if growth increased by 1%, it would raise the interest rate by ϕ%.

(viii) Conventional Monetary policy

This section uses the theory I have developed to explain the history of inflation since WWII. Using the classical model as the basis for a calibrated example, I will examine how different values of $\bar{I}$, η and ϕ, affect the inflation rate we would expect to see in different states in a rational expectations equilibrium.[11]

I will assume that output growth in each state, $\Delta y(s)$, is independent of inflation. Despite the simplicity of my example, the ideas I will describe carry over to more realistic models in which central bank policies affect, not only inflation, but also GDP and real economic activity.

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unemployment rate. For an excellent critique of the new-Keynesian approach from a classical perspective, see Chari-Kehoe-McGrattan (2009).

[11] The values of inflation and the interest rate reported in Tables 2 and 4 are the solutions to the non-linear equations (12) and (13), computed using Matlab. The code is available from the author on request.

Table 1	Assumptions about model parameters				
Time preference	Risk aversion	Probability of staying in state a	Probability of staying in state b	Growth rate in state a	Growth rate in state b
β	ρ	$p_{a,a}$	$p_{b,b}$	$\Delta y(a)$	$\Delta y(b)$
0.97	2.0	0.9	0.95	4%	1%

Table 1 summarizes the values of the time preference parameter, the risk aversion parameter, and the probabilities that the economy will stay either in state a, or in state b. I have assumed that state a is a high growth state in which GDP grows by 4% per year and that state b is a low growth state where GDP growth is 1%.

Table 2	The effect of changing the inflation response					
$\bar{I}$	η	ϕ	$\pi(a)$	$\pi(b)$	$I(a)$	$I(b)$
1.05	1.1	0	37.7%	13.6%	49.2%	20.8%
1.05	2	0	5.1%	0.06%	15.9%	6.4%

Table 2 compares two different policy rules, chosen to illustrate the difference between the policies followed before 1979 and after 1983. The zero-inflation target is 5% for both policies but in row 1 the Fed chooses an inflation reaction coefficient of $\eta = 1.1$ and in row 2 it chooses a larger coefficient of $\eta = 2.0$.

Row 1 is an example of a less aggressive monetary policy of the kind that was followed before 1979 and row 2 is a more aggressive policy of the kind followed after 1983.[12] Notice that the less aggressive monetary policy leads to inflation rates in states a and b of 37.7% and 13.6% with corresponding interest rates of 49.2% and 20.8%. These inflation rates are high and volatile.

Contrast this with the policy of the more aggressive regime (row 2) which leads to inflation rates of 5.1% and 0.06% and interest rates of 15.9% and 6.4%, numbers which are smaller and less volatile than those in row 2. The only difference between these two examples is the inflation-reaction coefficient of the Taylor Rule. It follows that a central bank can produce low and stable inflation in the model environment by choosing a policy rule with a high inflation-reaction coefficient.

[12] Some estimates place the parameter η less than 1. This is called a *passive* policy in the literature as opposed to a value greater than 1 that is called *active*. I have not gone all the way to a passive monetary policy in my simulations since passive policies introduce an additional complication; there may be additional *non-fundamental states* in a steady state. For a full discussion of this possibility in the context of U.S. monetary policy, see the article by Clarida, Galí, Gertler (2000).

This result corresponds to what econometricians have found (for example, Lubik and Schorfheide 2004) when examining the time series data. During the period from 1951 through 1979, monetary policy was less aggressive and inflation was high and variable. During the period after 1983, policy was more aggressive, and inflation was lower and less volatile.

(III) Part 2: Monetary policy at the zero lower bound

(i) Monetary policy as a rule

One of the lessons of post-war monetary policy is that policies are best modeled as rules rather than as discretionary events. Expectations matter, and when the central bank repeats the same actions in the same circumstances, agents in the economy learn to respond in a particular way. But monetary policy rules are not set in stone. They can and do change from time to time as policy evolves in response to changing circumstances and as policy makers learn from experience. When the policy rule changes, there will be a period where households and firms learn to respond to the new rules of the game. The current crisis has engendered one such period of adaptation and change as the rule used to conduct policy over the past thirty years has broken down.

The need to adapt monetary policy to a new set of circumstances has led to a dilemma since the rule that worked well in the period after 1983 cannot easily be adapted to the current crisis in which the interest rate is at zero. The following example illustrates this dilemma by showing that an alternative rule might have prevented a period of deflation like the one that occurred after the collapse of Lehman Brothers in 2008. But moving to an alternative rule cannot be achieved through conventional means.

I will illustrate the dilemma by means of an example. Table 3 shows the parameters for a simulated economy that grows at 4% in a state *a*, but where it shrinks by 5% per year in state *b*. All other parameters in this Table are the same as for the previous example.

Table 3	Modeling a recession				
Time preference	Risk aversion	Probability of staying in state *a*	Probability of staying in state *b*	Growth rate in state *a*	Growth rate in state *b*
β	ρ	$p_{a,a}$	$p_{b,b}$	$\Delta y(a)$	$\Delta y(b)$
0.97	2.0	0.9	0.95	4%	-5%

Under these assumptions about growth rates, the policy rule described by Equation (14), and the reaction functions from Table 2, lead to situations where the central bank would need to choose a negative nominal interest rate in state *b*. Since the interest rate cannot be negative, this set of fundamentals leads the central bank into a liquidity trap, that is, a situation where the interest rate cannot be lowered further. To represent this constraint, I have amended the Taylor rule, Equation (14), as follows,

$$r[\pi(s), \Delta y(s)] = \max\left[\bar{I}\pi^{\eta}\Delta y^{\phi}, 1\right]. \tag{15}$$

This rule bounds the gross return $(1 + i)$ to be no smaller than 1 by setting the interest rate to zero in those situations where a policy maker, following Equation (14), would prefer to choose an interest rate that was negative.

Table 4 shows what would happen to inflation in this economy under two possible choices for the Taylor rule. In both cases, the Fed chooses an inflation response coefficient of 2; but the zero-inflation target differs across the two policies. Both rules impose the zero lower bound.

Table 4	The effect of changing the inflation response					
$\bar{I}$	η	ϕ	$\pi(a)$	$\pi(b)$	$I(a)$	$I(b)$
1.05	2	0	3.4%	-2.4%	12.3%	0%
0.99	2	0	9.3%	0.05%	18.3%	0%

Row 1 shows what would happen to inflation in both states if the zero-inflation target is 5%, represented by setting the parameter $\bar{I}$ equal to 1.05. Row 2 shows the outcome when it is set to negative 1%. Under the 5% rule, we see that there would be deflation in state *b* of 2.4%. But if the Fed were to move to rule 2 with a negative zero-inflation target, there would be a mild inflation in state *b* of 0.05%. Both rules hit the zero lower bound for the interest rate in state *b*. The difference in inflation across the two rules is enforced by what households and firms expect the Fed to do in the future.

(ii) The Theory of unconventional monetary policy

Much of the recent policy debate on unconventional monetary policy has focused around the issue: How can the Fed signal its intention to change future monetary policy in a credible way? The credibility issue arises, because, when the interest rate is zero, there is no way to signal a change of policy to the markets using conventional open market operations. The purchase and sale of treasury bills has no effect on the economy, because, when the interest rate is zero, treasury bills and money become perfect substitutes. Monetary policy becomes like "pushing on a string". That's where unconventional monetary policy comes in.

The two policies described in Table 4 both result in a zero interest rate in state *b*. That causes a problem for a central bank that wishes to signal a change in policy, since it is expectations of future policy that enforce a particular inflation rate in the current period.

Suppose that the central bank has been following rule 1 for a period and that the public has conditioned its expectations on the assumption that rule 1 will continue to be used in the future. That rule leads to a deflation of 2.4% in a deep recession, an outcome that is undesirable to a policy maker who would prefer to maintain a positive inflation rate.

Let us suppose, that finding itself in a situation of deflation, the Fed would like to switch to rule 2. A move to rule 2, while in state *b*, leads to a policy dilemma. The bank cannot credibly signal it's switch to the new rule by buying or selling treasury bills since both rules lead to a zero interest rate in that state.

But although both rules lead to the same interest rate in state *b*; they are associated with *different* pricing kernels. If we let $Q_1(s,s')$ be the pricing kernel under policy 1 and $Q_2(s,s')$ be the pricing kernel under policy 2 then, it is true that

$$Q_i(b,a')+Q_i(b,b')=1, \quad \text{for} \quad \mathrm{i}=1{,}2. \tag{16}$$

That is simply the statement that the interest rate is equal to zero in state *b* under both policy rules. But that does not imply that this equality holds for each security, in other words,

$$Q_1(b,a') \neq Q_2(b,a') \text{ and } \quad Q_1(b,b') \neq Q_2(b,\mathrm{b}'). \tag{17}$$

This implies that there are other securities that are traded in the financial markets that would not have the same price under the two different policy rules. One example is a long-term government bond; another is a mortgage-backed security issued by the private sector. By intervening in the markets for alternative assets of this kind, a central bank can signal its intent to operate a different policy rule in future states.

(IV) Part 3: Evidence for the effectiveness of unconventional monetary policy

(i) The effect of QE1 on inflationary expectations

The theory of financial markets in a stationary environment predicts that central bank interventions in the asset markets can influence asset prices.[13] But what evidence is there that these kinds of interventions have worked in practice?

[13] Eggertsson and Woodford (2003) have argued that the composition of the Fed's balance sheet is irrelevant in a complete markets economy like the one used in my example. But their irrelevance proposition does not preclude the use of changes in the Fed's balance sheet as a signal to the public that the policy rule has changed and that the Fed's reaction to inflation in future states will be different. Further, their irrelevance proposition rests on the assumption that all changes in seigniorage revenues to the central bank are distributed back to households as lump-sum transfers, an assumption that clearly does not hold in the real world.

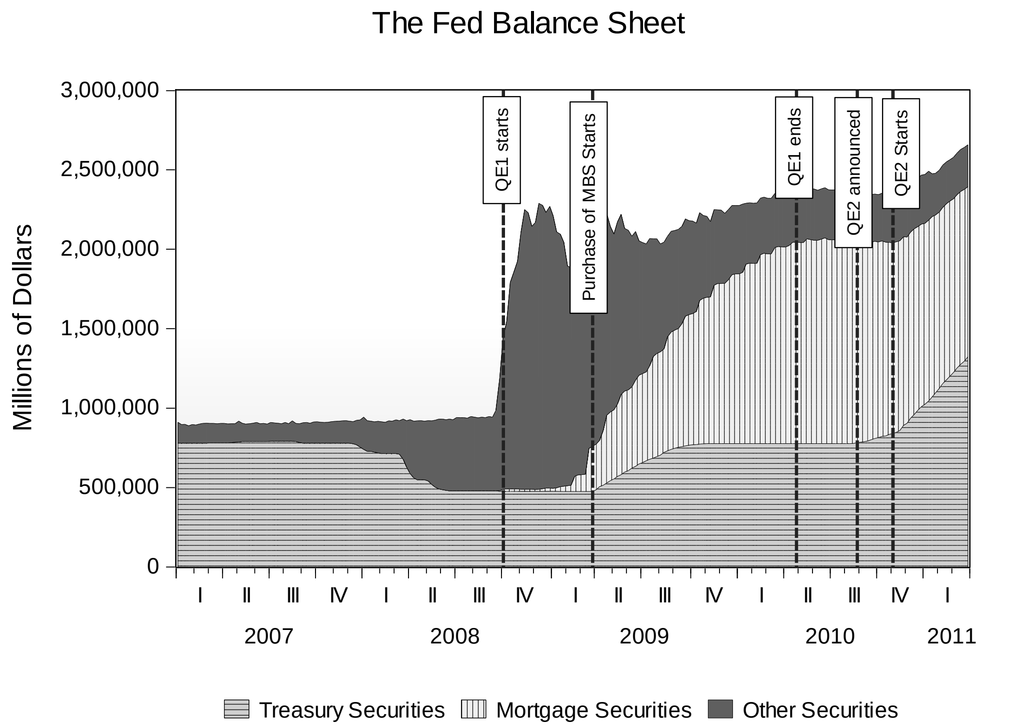

Figure 1: The balance sheet of the Fed

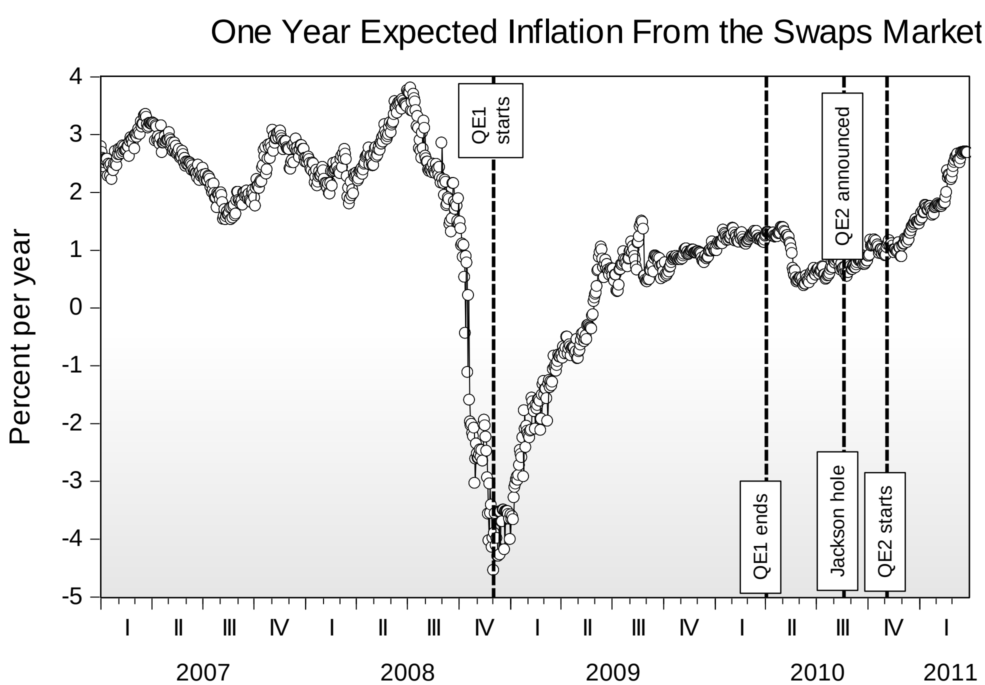

Figure 2: The effect of QE on inflation expectations

Figure 1 shows how the Federal Reserve Bank responded to the recession that began in December of 2007 and escalated rapidly in September of 2008. The figure breaks down the balance sheet of the Fed into three separate components, treasury securities, mortgage securities and other securities. Much of this last component consists of loans to the holding company, Maiden Lane, created specifically to rescue the financial sector.

Notice from Figure 1, that the balance sheet of the Fed increased from approximately $800b in 2007 to over $2,000b immediately following the Lehman Brothers bankruptcy in September of 2008. This increase did not arise from the purchase of treasury securities, the method of operating monetary policy in normal times; it arose instead from the purchase of risky securities that pay different amounts in different states. In terms of the theory developed in this essay, this implies that the Fed was not buying an equal weighted basket of all Arrow securities. It was buying a basket with very different payouts across alternative states of nature.

Figure 2 shows a measure of one-year inflation expectations taken from a derivate security in the asset markets. This is the value of expected inflation implied by a swap in which one party makes a payment to the other at the end of the contract.[14] On December 2nd 2008 expected inflation from the one year swap market was -4.5%. Traders were pricing an expected deflation rate of 2.24% into their behaviors. From that date on, inflationary expectations increased steadily returning to the range of plus 1% by the fall of 2009. It is unlikely that the correlation between the change in expectations, and the implementation of the new policy of quantitative easing, was coincidental.

(ii) The effect of QE1 on the stock market

Under the policy of quantitative easing, the Fed has purchased two major classes of assets; mortgage-backed securities and long-term government bonds. Long-term treasury bonds and mortgage-backed securities can both be expressed as weighted sums of Arrow securities; they differ only in the weights attributed to each state dependent payoff. The fact that these weights are different implies that Fed purchases of long bonds will impact the securities markets differently from Fed purchases of mortgage-backed securities.

Fed purchases of five-year or ten-year treasury bonds have their most direct effect on the prices of corporate bonds of a similar maturity; these private debt instruments represent combinations of Arrow securities with a similar weighting pattern to those of equal maturity government debt instruments.

In contrast, mortgage backed securities have high payoffs when the economy is strong since in these states there will be fewer mortgage defaults. The prices of mortgage-backed securities

[14] In an earlier version of this paper I used a measure of inflation derived from the difference between the nominal yield on a five-year bond and the real TIPS yield. I am indebted to Hanno Lustig for providing me with data from a one year swap. Fleckenstein et. al. argue that this is a better measure of expected inflation due to pricing anomalies in the TIPS yields around the time of the Lehman bankruptcy.

should move closely with the prices of equity shares in private corporations since both classes of assets have high payoffs when the economy recovers.

Some evidence for this supposition is provided in Figure 3 which shows what happened to the value of the S&P 500 when the Fed began purchasing mortgage backed securities in March of 2009. The date at which this purchase began, and the date at which the first round of quantitative easing came to an end, are marked with dashed vertical lines on this figure. Notice the close connection between the end of a bear market in March of 2009 and the beginning of large-scale purchases in the MBS market (see Figure 1). Notice also that the bull market ended with a sharp reversal in April of 2010, a date that coincides with the removal of the Fed program to purchase risky assets.[15]

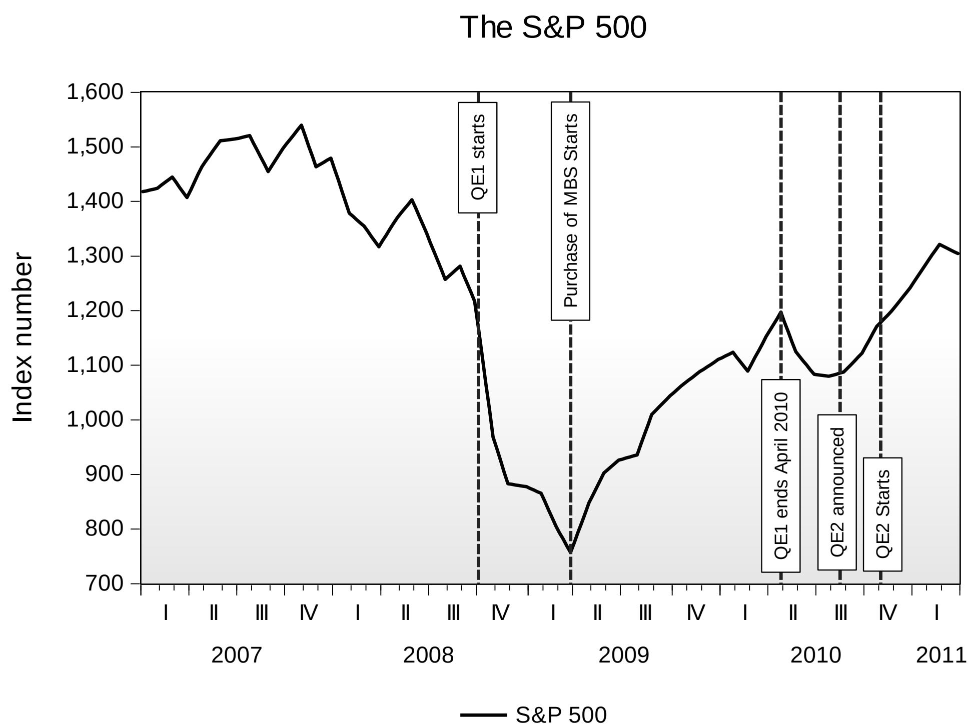

Figure 3: The effect of QE on the stock market

The announcement of a second round of quantitative easing occurred at the Jackson Hole conference in August of 2010. Although the policy itself did not begin until November of the same year, Figure 3 illustrates that the announcement of the policy coincides closely with the date at which there was another major reversal in the stock market.

[15] Kuttner (2006) finds evidence of the effectiveness of Fed policies on long bond prices over the period from 1941 through 2003. For a comprehensive study of the effects of QE in the most recent period, using an event study, see Krishnamurthy and Vissing-Jorgensen (2011).

(V) Conclusion

The practice of central banking and the development of new economic ideas are part of an evolutionary process that is fed by economic events. Large disruptive events are few and far between. The financial panic of 1907 led to the creation of the Fed. Since its inception, the Fed, along with other central banks worldwide, has been accumulating knowledge about the structure of the economy and applying that knowledge in its day to day operations.

The Great Depression of the 1930's led to widespread agreement that government has an obligation to maintain full employment. In the U.S., this idea was enshrined in the Employment Act of 1946. Since that date, the Fed intervened actively to shorten recessions by lowering the interest rate when signs of weakness appeared. Casual inspection of the data suggests that this policy has been effective as postwar business cycles have been considerably less volatile than those that preceded them in the nineteenth and early twentieth centuries.

The appearance of stagflation in the 1970s led to a second change in policy as the Fed began to adopt a more aggressive response to inflation. Academic economists responded by developing the theory of rational expectations and by arguing that central banks should follow policy rules. Central banks responded by adopting inflation targeting and by following more aggressive rules to stabilize inflation. The change from less aggressive to more aggressive responses to nascent inflation was accompanied by a reduction in the volatility of U.S. business cycles.

The Great Recession is a further game changing event. In the wake of the 2008 financial crisis, we have seen policy makers experiment with unconventional monetary policy in an attempt to regain control of inflation and unemployment in an environment where traditional policy instruments no longer work. My contribution in this essay has been to provide a unified framework to understand how an interest rule can be used to control inflation in normal times, and to explain the purpose of unconventional monetary policy when policy attains the zero lower bound. Unconventional monetary policy is an important tool in a central bank's arsenal that can be used to help prevent deflation in the wake of a financial crisis.

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