DR 08006

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MARCH 2008

ESSEC

CENTRE DE RECHERCHE

- DR 08006 -

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February 2008

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ABSTRACT:

Financial Newspapers have for long suggested that the Fed tends to provide additional Liquidity when the Stock Market thumbs. We provide a theoretical Explanation for this Behaviour that builds on the Methodology developed by Romaniuk (2008) for a central Banker with two main Goals, Output and Price stability. In this Paper, the Policymaker behaves as a Portfolio Manager who aims at stabilizing Output, Goods Prices, as well as Asset Prices. An optimal, Time-varying Interest Rate Rule is obtained as the Merton's (1971) continuous Time Solution to the Portfolio Manager's Problem. In a second Step, we infer the optimal Interest Rate Rule of a central Bank that can react differently to positive and negative Variations in the Stock Market.

Key-Words:

- Optimal Interest Rate Rule
- Portfolio Choice
- Fed
- Asset Prices
- Options Theory

RESUME :

L'article propose plusieurs estimations de la règle de Taylor de la Fed et met en relief sa réponse asymétrique par rapport aux prix des biens et des actifs. Une explication est apportée, en s'appuyant sur l'approche développée par Romaniuk (2008). Dans cette perspective, la règle de décision du banquier central apparaît comme la solution de Merton (1971) au problème du gestionnaire de portefeuille, en supposant que le banquier central assure la gestion de trois "actifs": prix des biens, production et prix des actifs.

Mots-clés :

- règle monétaire optimale
- choix de portefeuille
- Fed
- prix des actifs
- théorie des options

JEL classification : E58, G11, C61

March 3, 2008

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Abstract

According to empirical evidence brought in by this paper, the Fed seems to respond stronger to positive than to negative deviations in inflation from trend; it also presents an asymmetric response with respect to asset prices. We provide a theoretical explanation that builds on the methodology developed by Romaniuk (2008) for a central banker with two main goals, output and price stability. In this paper, the policymaker behaves as a portfolio manager who aims at stabilizing output, goods prices, as well as asset prices. An optimal, time-varying interest rate rule is obtained as the Merton's (1971) continuous time solution to the portfolio manager's problem. In a second step, option terms are included in the interest rate rule, in order to allow the central bank to react differently to positive and negative deviations of key variables from their targets.

Keywords: optimal interest rate rule, portfolio choice, stochastic dynamic programming, Fed, asset prices, options theory.
JEL Classification: E58, G11, C61.

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1 Introduction

Starting with the pioneering paper by Taylor (1993), it became the norm in monetary economics to describe the central bank behavior by means of a simple interest rate rule. In such a framework, the central bank is assumed to steer the main monetary instrument, in general a short-term interest rate, depending on variations in variables assumed to have an impact on its main objectives. While such an interest rate rule can easily be inferred from the data, it appears as much more difficult to determine the actual objectives of the central banker by merely observing such an estimated rule. However, these intrinsic objectives can be related to the official goals of the policymaker.

For instance, according to his statute, the US Fed must "conduct the nation's monetary policy by influencing the monetary and credit conditions in the economy in pursuit of maximum employment, stable prices, and moderate long-term interest rates". Unlike the European Central Bank, whose official mission sets almost exclusive emphasis on price stability, the Fed is expected to strike an adequate balance between protecting employment and maintaining price stability.

The Fed has also been assigned an official objective of "supervising and regulating banking institutions to ensure the safety and soundness of the nation's banking and financial system..." as well as "maintaining the stability of the financial system and containing systemic risk that may arise in financial markets". It is not clear however whether this latter goal should be achieved only through regulation and supervision, or by active management of the interest rate.[1]

In general, top Fed officials have systematically denied that they have a direct goal of stabilizing asset prices. Yet many observers – financial newspapers but also a few economists – have noticed that the Fed seems to reduce interest rates whenever the financial market goes into troubles, while no response is observed when asset prices go up. This asymmetric response was often referred to by the popular press as the "Greenspan put", and tends to become now the "Bernanke put". Indeed, during the current financial crisis originated in the subprime mortgage market, the Fed has reduced the target rate by one percentage point in the fourth quarter of 2007, at a period where

[1] Asset prices have been for long a subject of controversy for monetary economists. The yet unsettled theoretical debate turns around the question of whether the inclusion of asset prices into the interest rate rule of a central banker would improve or not the overall stability of the economy. See for instance Bernanke and Gertler (1999) and Bullard and Schaling (2002) for arguments against including asset prices, Cecchetti et al. (2000) and Romaniuk (2006), for the opposite view.

inflationary tensions were not negligible (oil prices kept on rising and the dollar was extremely weak). A further reduction of 1.25 % has been decided during January 2008. Explanations for this idiosyncratic behavior were worked out by Miller et al. (2002), Illing (2004) and Sauer (2007). In general, in their models, the Fed would provide liquidity in order to prevent the financial disruption from taking its toll on output growth.

In this paper, we bring some additional empirical evidence that backs the assumptions according to which the Fed interest rate rule seems to incorporate asset prices and presents asymmetric responses to positive vs. negative goods and stock price variations. We then infer a Fed-suited optimal interest rate rule, drawing on the original methodology developed by Romaniuk (2008). She analyzed the optimization problem of a central banker who behaves like a two asset portfolio manager aiming at stabilizing good prices and output. The solution builds on Merton (1971)'s continuous time asset allocation problem. Here we extend this analysis, to take into account the fact that the Fed has actually three main official goals: price stability, output sustainability and financial stability. To assess financial stability, the empirical analysis takes into account the stock market index, and we refer to the same indicator in the theoretical analysis, knowing that several variables may be used as a proxy for financial stability (the bid-ask spread, house prices, etc.). Another development undertaken in this paper is to analyze the decision rule of a central banker which reacts in an asymmetric way to positive/negative deviation of the key variables from their targets. For so doing, we first show that these asymmetries can be mathematically translated into options - calls and puts - to be included in the interest rate rule. The optimal portfolio rule for a central bank conducting an asymmetric monetary policy is then obtained by solving a similar Merton problem.

When compared with the existing economic methodology, which consists in inferring an optimal interest rate rule à la Taylor (1993) from a simple model of the economy, assuming linear dynamics for inflation and the output gap, and a quadratic objective function of the policymaker (Svensson, 1997; Rudebusch and Svensson, 1998), the financial approach brings several improvements. First, it is developed in a fairly more general setting: linear relations are no more imposed and the parameters of the key variable dynamics can obey time-varying and complex formulations. Second, as the solution to a dynamic optimization problem, the rule evolves with the state of the economy, which in turn depends on expectations, variances and covariances of variation rates in the key variables. Third, the form of the optimal interest rate rule can be easily interpreted in the light of well-known principles driving the portfolio manager's behavior, such as the diversification motive. And last, as will be shown in this paper, the model is quite flexible and can be easily adapted to various economic contexts. We will focus here on two rules that seem to be the most relevant for the Fed case: where the central bank has not only the goal of promoting employment and maintaining price stability, but also aims at preserving financial stability, and where the decision rule is asymmetric with respect to deviations from predetermined targets.

The paper is organized as follows. The next Section provides several estimates of the Fed interest rate rule over the period 1971-2007. In Section 3, the portfolio manager model, such as applied to a three-goal central banker, is solved for an optimal interest rate rule. In Section 4, the policy rule is generalized to account for possible asymmetric responses of the central banker to changes in main variables with respect to their predetermined targets. The last section concludes the paper.

2 An empirical assessment of the Fed's interest rate rule

In this section, we work out several estimates of the Fed's interest rate rule in the interval 1971 Q1 - 2007 Q1. The general form writes:

$$r_t = c + \lambda r_{t-1} + (DUM80 + DUM90)A\mathbb{Z} + \varepsilon_t, \tag{1}$$

with r the short-term interest rate, λ is related to the speed of the adjustment[2] , A is a vector of coefficients, and $\mathbb{Z}$ a vector of dependent variables that capture the three main goals of the Fed: the inflation rate as a proxy for price stability, the output gap as a proxy for sustainable growth, and the stock market index as a proxy for financial stability. ε_t is an i.i.d. shock. Long-run coefficients are thus A/λ.

The main OLS results are displayed in Table 1. The dependent variable, FFRUSED, is the quarterly average of the effective federal funds rate.

[2] Each quarter the Fed will close the gap between the actual and the desired interest rate by $(1 - \lambda)$.

Right hand side variables are :

- CPINSA is the inflation rate based on the US CPI, measured this quarter to the same quarter of the previous year. Based on this series, we extract the HP trend from the inflation series (CPINSA_HP) and calculate the gap between actual data and trend values: CPIGAP=CPINSA-CPINSA_HP. We then create two other series, CPINSA_UP=max{0, CPIGAP} and CPINSA_DWN=min{0, CPIGAP}. The former reports only the positive deviations and takes the value zero for all negative deviations, the latter contains only the negative deviations and takes the value zero for positive deviations.

- GDPGAP is the output gap, measured as the percent deviation in the output index with respect to its HP trend. Based on this series, we generate two others: GDPGAP_UP=max{0, GDPGAP} and GDPGAP_DWN=min{0, GDPGAP}.

- DSP500 is the variation in the Standard & Poors 500 stock market index (from this quarter to the same quarter of previous year, in percent); we also split the main series into DSP500_UP=max{0, DSP500} and DSP500_DWN=min{0, DSP500}.

- DUM80, DUM90 are dummy variables which take the value 1 for quarters after Q1 1980 (and respectively Q1 1990). Many observers suggested that the Fed operated a policy break between 1979 and 1982 ; we also allowed for such a break in the nineties.

- FFRUSED(-1), the lagged interest rate, was introduced in order to capture the smoothing effect.

Many economists have documented breaks in the behavior of the Fed. In general experts tend to agree on that a first break occurred between 1979 and 1982, when Paul Volker adopted a very aggressive anti-inflation policy (Meltzer, 2006; Orphanides, 2006). Less well documented, it seems that another break occurred during the nineties, a period where the Fed gradually played down the information conveyed by monetary aggregates in the conduct of monetary policy (Friedman, 2006). In order to authorize such would-be structural breaks, we include in some of our estimates, as a multiplicative coefficient of A, two dummy variables, $DUM80$, which takes the value one after Q1 1980, and $DUM90$, which takes the value one after Q1 1990.

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
C	0.049^{ns}	0.381^{ns}	0.184^{ns}	0.542*	0.547*	0.446**	1.078***
FFRUSED(-1)	0.890***	0.830***	0.892***	0.825***	0.830***	0.918***	0.864***
DUM80*CPINSA(3)	–	0.104**	–	0.109**	0.103**	–	0.192^{ns}
DUM90*CPINSA(3)	–	-0.140**	–	-0.151**	-0.147**	–	-0.666**
CPINSA(3)	0.124***	0.122***	0.127***	0.114***	0.120***	–	–
CPINSA_UP(3)	–	–	–	–	–	0.280**	0.278**
CPINSA_DWN(3)	–	–	–	–	–	-0.043^{ns}	0.064^{ns}
GDPGAP	0.205***	0.217***	–	–	0.195***	–	–
GDPGAP_UP	–	–	0.155^{ns}	0.247**	–	0.189^{ns}	0.147^{ns}
GDPGAP_DWN	–	–	0.205***	0.155^{ns}	–	0.188^{ns}	0.169^{ns}
DSP500(-1)	0.011**	0.009*	–	–	–	–	–
DSP500_UP(-1)	–	–	0.004^{ns}	0.001^{ns}	0.001^{ns}	0.001^{ns}	0.001^{ns}
DSP500_DWN(-1)	–	–	0.026*	0.026*	0.025*	0.026*	0.029*
R2a	*0.932*	*0.936*	*0.930*	*0.933*	*0.933*	*0.926*	*0.929*
DW	*1.94*	*1.93*	*1.94*	*1.94*	*1.94*	*1.88*	*1.88*

Legend: *** significant at 1%, ** at 5%, * at 10%. ns - non significant

Table 1. Estimates of the Fed interest rate rule

Equation 1 in Table 1 is a standard forward-looking Taylor rule augmented by the variation in the stock market. The smoothing coefficient is 0.11, so the long-run coefficient of inflation (β) is equal to $0.124/0.11 = 1.13$, while the long-run coefficient of the output gap (γ) is 1.86. The variation in the stock market has a long-run coefficient $\theta = 0.011/0.11 = 0.1$. It appears that, at the first sight, each time the stock market rises *or* falls by 10%, the Fed will increase/decrease the interest rate by one percentage point. Equation 2 performs the same analysis, but the introduction of dummy variables multiplicative of the coefficient of inflation allows to take into account possible changes in the strictness of the anti-inflation policy. It turns out that in the eighties, the Fed response to inflation deviations was quite strong (this is a well documented outcome); in the nineties, a period of joint low inflation and high growth driven by large productivity gains, the bank reacted less strongly to inflation deviations from target.

Dolado et al. (2005) have already put forward the asymmetric response of the Fed with respect to inflation and the output gap. We also carry out several estimates where we distinguish between the positive and the negative deviation of output from the HP trend, positive and negative deviation of inflation form the HP trend and between positive and negative variations in the stock market. The estimates do not put forward a strong difference between the response of the bank to positive and negative deviations of the GDP from its trend. At difference with Dolado et al. (2005), who, in the case of the Fed (only) could not reject the assumption of a symmetric response to inflation deviations, our estimates (Eq. 6 and 7 in Table 1) suggest that the Fed reacts much stronger to upward deviations of inflation from its HP trend than to downward deviations.

More important for our analysis, there is a sharp contrast between the relatively strong response of the Fed to declines in the stock market and its "benign neglect" with respect to the stock market rises. For instance, in Equation 5, with a smoothing coefficient of 0.17, the long-term coefficient on the negative variation in the stock market is $0.025/0.17 = 0.147$; whenever the stock market declines by 10%, the Fed will reduce its interest rate by 1.5 percentage points. In the same equation, the coefficient on stock market positive variations is close to zero and not statistically significant. This outcome is robust across all our estimates (Eq. 3-7 in Table 1) and brings support to the "Greenspan put" hypothesis.

We can turn now to the theoretical explanation for this behavior. In particular, we aim at inferring an interest rate rule which takes into account the financial stability goal.

3 Optimal monetary policy of a central bank concerned with financial stability

In his pioneering paper, Taylor (1993) surmised that the Fed's interest rate rule can be described as a linear function in the inflation rate and the output gap. We follow this line of reasoning by assuming that the level of the monetary policy instrument r depends linearly on variables X_i (with $i = 1, 2, ..., N$):

$$r(t) = \sum_{i=1}^{N} \lambda_i(t) X_i(t) \tag{2}$$

with λ_i the weight assigned by the policymaker to the variable X_i when choosing the value of r. At difference with traditional literature that uses as relevant variables the deviations from normal values, in this paper we follow the analysis of Romaniuk (2008) and work with variables in levels. A difference with that paper must however be emphasized: while Romaniuk (2008) assumed that the interest rate level depends on two variables (the price index and output), we introduce here a third key variable, asset prices, as approximated by the stock price index. By doing so, we take into account the three main official objectives of the Fed, which are: maintaining price stability in the goods market, supporting growth and employment and guaranteeing financial stability. In our framework, we have $i = 1, 2, 3$, with $X_1 \equiv P$, $X_2 \equiv Y$ and $X_3 \equiv S$, P denoting the price index, Y output and S the stock price. In what follows, we will continue to work with the general setting given by Eq. (2), since it can be easily transposed to other monetary policy environments than the one under scrutiny.[3]

>From a financial perspective, it can be considered that the variable r is invested in the assets X_i in the proportions $\delta_i(t) \equiv \dfrac{\lambda_i(t) X_i(t)}{r(t)}$, with $\sum_{i=1}^{N} \delta_i(t) = 1$. Then, the dynamics of r writes:

$$\frac{dr(t)}{r(t)} = \sum_{i=1}^{N} \delta_i(t) \frac{dX_i(t)}{X_i(t)} \tag{3}$$

One here needs to define the variable X_i dynamics. The following stochastic differential equation

[3] For example, one could think of a central bank interested in maintaining goods price stability only, which is theoretically the case of the ECB ($i = 1$, $X_1 \equiv P$), or of the one containing inflationary pressures and supporting growth ($i = 1, 2$, $X_1 \equiv P$, $X_2 \equiv Y$). The setting could also reflect the case of a central bank aiming at goods price stability, maximum sustainable growth, financial stability, yet also exchange rate stability. We then have $i = 1, 2, 3, 4$, with $X_1 \equiv P$, $X_2 \equiv Y$, $X_3 \equiv S$ and $X_4 = e$, e denoting the exchange rate.

(SDE) describes the evolution of the variable X_i:

$$dX_i(t) = X_i(t)\mu_{X_i}(t, Z(t), r(t))dt + X_i(t)\sigma_{X_i}(t, Z(t), r(t))dB(t) \tag{4}$$

where $\mu_{X_i}(t, Z(t), r(t))$ is defined as a bounded function of t, Z and r, $\sigma_{X_i}(t, Z(t), r(t))$ a bounded $(1 \times M)$ vector valued function of t, Z and r, $B(t)$ an $(M \times 1)$-dimensional Wiener process in R^M, $Z(t)$ a $(K \times 1)$-dimensional vector of state variables.

The dynamics of the N variables X_i can be written in a compacted form:

$$dX(t) = I_X\mu_X(t, Z(t), r(t))dt + I_X\sigma_X(t, Z(t), r(t))dB(t) \tag{5}$$

with I_X denoting an $(N \times N)$ diagonal matrix valued function of $X(t)$ with $X_i(t)$ as its $i-$th diagonal element, $\mu_X(t, Z(t), r(t))$ an $(N \times 1)$-dimensional vector with $\mu_{X_i}(t, Z(t), r(t))$ as its $i-$th element, $\sigma_X(t, Z(t), r(t))$ an $(N \times M)$ matrix valued function with $\sigma_{X_i}(t, Z(t), r(t))$ as its $i-$th element.

The evolution of the economy is affected by K stochastic state variables. We have just defined $Z(t)$, the vector of state variables, as a $(K \times 1)$-dimensional vector. It is assumed that the N first variables composing Z are X_1, X_2, ..., X_N, and the $(K - N)$ remaining components are constituted by other stochastic variables influencing the main variable dynamics.

Z evolves according to the dynamics :

$$dZ(t) = I_Z\mu_Z(t, Z(t), r(t))dt + I_Z\sigma_Z(t, Z(t), r(t))dB(t) \tag{6}$$

where I_Z stands for a $(K \times K)$ diagonal matrix valued function of $Z(t)$, $\mu_Z(t, Z(t), r(t))$ a bounded $(K \times 1)$ vector valued function of t, Z and r, $\sigma_Z(t, Z(t), r(t))$ a bounded $(K \times M)$ matrix valued function of t, Z and r.[4]

One can now replace the X_i dynamics, as given by Eq. (4), in Eq. (3) to finally obtain:

$$\frac{dr(t)}{r(t)} = \delta(t)'\mu_X(t, Z(t), r(t))dt + \delta(t)'\sigma_X(t, Z(t), r(t))dB(t) \tag{7}$$

with δ an $(N \times 1)$ vector of the proportions of the r variation rate driven by the X_i variation rates, and the prime $(')$ standing for a transpose.

[4] The definition of the main variable and state variable dynamics is based on Lioui and Poncet (2003) and Romaniuk (2007).

The central bank aims at maximizing its expected intertemporal utility over the monetary policy horizon, which is mathematically translated in the following formulation, at date t:

$$\max E_t \left[\int_t^T U\left(r(s), Z(s), s\right) ds \right] \tag{8}$$

where E_t stands for the expectation conditional on the information available at date t, T the monetary policy horizon, U the utility function.

It is assumed that the utility function is strictly concave in r. It is increasing, and then decreasing with respect to r. The utility maximum is defined for the interest rate which minimizes the deviations of the variables X_i from their targeted values.

The optimization program of the central bank thus is: maximize Eq. (8) with respect to δ, subject to the constraints of the r and Z dynamics, as defined by Eqs. (7) and (6) respectively.

The central bank optimization program is solved by applying the method of stochastic dynamic programming.

Let us first define the indirect utility function J:

$$J(r(t), Z(t), t) \equiv \max_{\delta(s)} E_t \left[\int_t^T U(r(s), Z(s), s) ds \right] \tag{9}$$

with J strictly concave in r and twice differentiable with respect to r and Z.

The Bellman optimality conditions impose:

$$0 = \max_{\delta(t)} \left[U(r(t), Z(t), t) + DJ(r(t), Z(t), t) \right] \tag{10}$$

with D the Dynkin operator.

The Dynkin of J is defined by:

$$DJ = J_t + J_r r \mu_r + \frac{1}{2} J_{rr} r^2 \Sigma_{rr} + (I_Z \mu_Z)' J_Z + \frac{1}{2} tr\left(I_Z \Sigma_{ZZ} I_Z' J_{ZZ}\right) + r \Sigma_{rZ} I_Z' J_{rZ} \tag{11}$$

where subscripts on J denote partial derivatives, $\Sigma_{ij} \equiv \sigma_i \sigma_j'$ the covariance matrix of the variables i and j, and the r dynamics are considered in its general form $\frac{dr}{r} = \mu_r dt + \sigma_r dB$.

Let us note that the dependence with respect to t, δ, r and Z has been omitted in the preceding equation, for the ease of exposition purpose. From now on, we shall omit this kind of dependence, except when a risk of confusion occurs.

One needs now to replace in Eq. (11) the parameters of the r dynamics as given by Eq. (7). By deriving the resulting DJ formulation with respect to δ, we get the system of first order conditions:

$$0_N = \mu_X J_r r + \Sigma_{XX} \delta J_{rr} r^2 + \Sigma_{XZ} I'_Z J_{rZ} r \tag{12}$$

This yields the optimal vector of proportions δ:

$$\delta = -(\Sigma_{XX})^{-1} \mu_X \frac{J_r}{J_{rr} r} - (\Sigma_{XX})^{-1} \Sigma_{XZ} I'_Z J_{rZ} \frac{1}{J_{rr} r} \tag{13}$$

The solution to this optimization program is made up of two terms: the speculative fund and the state variable hedge fund.

As outlined by Romaniuk (2008) in the two-asset case (i.e. when the monetary policy instrument is set relative to inflation and output), the speculative fund is representative of the traditional trade-off between risk and reward, or μ and σ: The fund absolute value increases with the expected variation rate of the given asset, and decreases when its standard deviation increases. Yet, as pointed out by Romaniuk (2008), there is an important difference between our setting, characterizing the central bank decision, and the standard portfolio management setting: Depending on whether an increase or a decrease in the interest rate is required, the sign of J_r is positive or negative, so that the speculative fund has an opposite sign in these two cases. This leads to the conclusion that *the central bank invests more heavily in the asset characterized by the best risk-reward properties only when an interest rate increase is needed.* When the state of the economy calls for an interest rate decrease, the opposite behavior is chosen.

Romaniuk (2008) took into account the central bank objectives of goods price stability and maximum sustainable growth. In this paper, in keeping with our empirical analysis, a third objective is included - the central bank also aims at preserving the good functioning of the financial market, or, in other words, to guarantee financial stability.

The first issue to be raised are then the consequences of introducing this additional objective on the portfolio behavior of the central bank. When incorporating a new asset in the portfolio, the optimal solution of the optimization program is modified: All the portfolio proportions now take account of the properties of the newly introduced asset, which are its risk-reward characteristics, and its covariance with the existing assets.

A second issue deserves an analysis: When is the introduction of a new term in the monetary policy reaction function justified? From a theoretical financial management perspective, the answer sounds rather simple. A new asset should be introduced in a portfolio whenever its financial properties are interesting, i.e. when its risk - reward - correlation (with the already existing assets in the portfolio) characteristics permit diversification.

Yet the question of introducing or not a possible asset in the portfolio is asked only for assets which can constitute a central bank objective. As a consequence, the financial properties of the given asset are far from being the only argument to be taken into account: If this were the case, the central bank would be theoretically advised to determine its monetary policy instrument level relative to a large number of assets. Provided that the former condition is met, i.e. the asset under scrutiny can be considered as a central bank objective, when will its incorporation in the monetary policy reaction function be justified? Here too the answer is straightforward: when its financial characteristics allow the policymaker to benefit from portfolio diversification.

4 Optimal monetary policy of a central bank with an asymmetric reaction function

The empirical analysis has shown that the Fed tends to react stronger to stock market negative variations, while it neglects positive variations. We also have shown that this asymmetry applies to inflation deviations from target (but not to output deviations). In order to account for this behavior, we introduce now an asymmetric monetary policy function where the central bank can react differently to positive and negative deviations of the X_i variables with respect to their targets. The monetary policy instrument is redefined as follows:

$$r(t) = \sum_{i=1}^{N} \lambda_i(t) X_i(t) + \sum_{i=1}^{N} \alpha_i(t) \left[X_i(t) - \overline{X_i}\right]^+ - \sum_{i=1}^{N} \beta_i(t) \left[\overline{X_i} - X_i(t)\right]^+ \qquad (14)$$

where $\overline{X_i}$ stands for the targeted level of the variable X_i. α_i represents the proportion of the positive deviation of X_i from target that is taken into account when fixing the interest rate level. Symmetrically, β_i determines the impact of a negative deviation on the r level chosen by the central bank.

One easily notices that the terms $\left[X_i(t) - \overline{X_i}\right]^+$ and $\left[\overline{X_i} - X_i(t)\right]^+$ in fact define the values of a call and a put respectively, which are written on X_i, with $\overline{X_i}$ as the strike price. Let us denote by C_{X_i} the value of the call and P_{X_i} the value of the put. One can then rewrite the definition of r :

$$r(t) = \sum_{i=1}^{N} \lambda_i(t) X_i(t) + \sum_{i=1}^{N} \alpha_i(t) C_{X_i}(t) - \sum_{i=1}^{N} \beta_i(t) P_{X_i}(t) \tag{15}$$

The interest rate dynamics follows:

$$\frac{dr(t)}{r(t)} = \sum_{i=1}^{N} \delta_i(t) \frac{dX_i(t)}{X_i(t)} + \sum_{i=1}^{N} \theta_i(t) \frac{dC_{X_i}(t)}{C_{X_i}(t)} - \sum_{i=1}^{N} \eta_i(t) \frac{dP_{X_i}(t)}{P_{X_i}(t)} \tag{16}$$

where the variable r is now invested in the assets X_i in the proportions $\delta_i(t)$, in the assets C_{X_i} in the proportions $\theta_i(t) \equiv \dfrac{\alpha_i(t) C_{X_i}(t)}{r(t)}$ and in the assets P_{X_i} in the proportions $\eta_i(t) \equiv \dfrac{\beta_i(t) P_{X_i}(t)}{r(t)}$, with the following identity: $\sum_{i=1}^{N} \delta_i(t) + \sum_{i=1}^{N} \theta_i(t) - \sum_{i=1}^{N} \eta_i(t) = 1$.

The variable X_i dynamics, as well as the Z dynamics, have already been defined. Let us now formulate the C_{X_i} and P_{X_i} dynamics:

$$dC_{X_i}(t) = C_{X_i}(t) \mu_{C_{X_i}}(t, Z(t), r(t)) dt + C_{X_i}(t) \sigma_{C_{X_i}}(t, Z(t), r(t)) dB(t) \tag{17}$$

$$dP_{X_i}(t) = P_{X_i}(t) \mu_{P_{X_i}}(t, Z(t), r(t)) dt + P_{X_i}(t) \sigma_{P_{X_i}}(t, Z(t), r(t)) dB(t) \tag{18}$$

where $\mu_{C_{X_i}}(t, Z(t), r(t))$ and $\mu_{P_{X_i}}(t, Z(t), r(t))$ are defined as bounded functions of t, Z and r, $\sigma_{C_{X_i}}(t, Z(t), r(t))$ and $\sigma_{P_{X_i}}(t, Z(t), r(t))$ bounded $(1 \times M)$ vector valued functions of t, Z and r.

The compacted form of the dynamics of the N variables C_{X_i} and N variables P_{X_i} can be written:

$$dC_X(t) = I_{C_X} \mu_{C_X}(t, Z(t), r(t)) dt + I_{C_X} \sigma_{C_X}(t, Z(t), r(t)) dB(t) \tag{19}$$

$$dP_X(t) = I_{P_X} \mu_{P_X}(t, Z(t), r(t)) dt + I_{P_X} \sigma_{P_X}(t, Z(t), r(t)) dB(t) \tag{20}$$

with I_{C_X} and I_{P_X} denoting $(N \times N)$ diagonal matrix valued functions of $C_X(t)$ and $P_X(t)$ respectively, $\mu_{C_X}(t, Z(t), r(t))$ and $\mu_{P_X}(t, Z(t), r(t))$ $(N \times 1)$-dimensional vectors, $\sigma_{C_X}(t, Z(t), r(t))$ and $\sigma_{P_X}(t, Z(t), r(t))$ $(N \times M)$ matrix valued functions.

The X_i, C_{X_i} and P_{X_i} dynamics, as given by Eqs. (4), (17) and (18), are replaced in Eq. (16).

One obtains:

$$\frac{dr(t)}{r(t)} = \left[\delta(t)'\mu_X(t,Z(t),r(t)) + \theta(t)'\mu_{C_X}(t,Z(t),r(t)) - \eta(t)'\mu_{P_X}(t,Z(t),r(t))\right] dt \qquad (21)$$
$$+ \left[\delta(t)'\sigma_X(t,Z(t),r(t)) + \theta(t)'\sigma_{C_X}(t,Z(t),r(t)) - \eta(t)'\sigma_{P_X}(t,Z(t)),r(t)\right] dB(t)$$

with θ and η $(N \times 1)$ vectors of the proportions of the r variation rate driven by the C_{X_i} and P_{X_i} variation rates respectively.

The optimization program of the central bank becomes: maximize Eq. (8) with respect to δ, θ and η, subject to the constraints of the r, Z, C_X and P_X dynamics, as defined by Eqs. (21), (6), (19) and (20) respectively.

The indirect utility function J is defined by:

$$J(r(t),Z(t),t) \equiv \max_{\{\delta(s),\theta(s),\eta(s)\}} E_t\left[\int_t^T U(r(s),Z(s),s)ds\right] \qquad (22)$$

with the Bellman optimality conditions given by:

$$0 = \max_{\{\delta(t),\theta(t),\eta(t)\}} \left[U(r(t),Z(t),t) + DJ(r(t),Z(t),t)\right] \qquad (23)$$

the Dynkin of J being once again formulated as in Eq. (11).

Let us replace the parameters of the r dynamics, as given by Eq. (21), in Eq. (11). The differentiation of the resulting DJ formulation with respect to δ, θ and η allows to obtain the system of first order conditions:

$$0_N = \mu_X J_r r + \left(\Sigma_{XX}\delta + \Sigma_{XC_X}\theta - \Sigma_{XP_X}\eta\right) J_{rr} r^2 + \Sigma_{XZ} I_Z' J_{rZ} r \qquad (24)$$
$$0_N = \mu_{C_X} J_r r + \left(\Sigma_{C_XC_X}\theta + \Sigma_{C_XX}\delta - \Sigma_{C_XP_X}\eta\right) J_{rr} r^2 + \Sigma_{C_XZ} I_Z' J_{rZ} r$$
$$0_N = -\mu_{P_X} J_r r + \left(\Sigma_{P_XP_X}\eta - \Sigma_{P_XX}\delta - \Sigma_{P_XC_X}\theta\right) J_{rr} r^2 - \Sigma_{P_XZ} I_Z' J_{rZ} r$$

The optimal vectors of proportions are then easily derived:

$$\begin{aligned}
\delta &= -(\Sigma_{XX})^{-1}\mu_X \frac{J_r}{J_{rr}r} \\
&\quad -(\Sigma_{XX})^{-1}\Sigma_{XC_X}\theta + (\Sigma_{XX})^{-1}\Sigma_{XP_X}\eta - (\Sigma_{XX})^{-1}\Sigma_{XZ}I'_Z J_{rZ}\frac{1}{J_{rr}r} \\
\theta &= -(\Sigma_{C_XC_X})^{-1}\mu_{C_X} \frac{J_r}{J_{rr}r} \\
&\quad -(\Sigma_{C_XC_X})^{-1}\Sigma_{C_XX}\delta + (\Sigma_{C_XC_X})^{-1}\Sigma_{C_XP_X}\eta - (\Sigma_{C_XC_X})^{-1}\Sigma_{C_XZ}I'_Z J_{rZ}\frac{1}{J_{rr}r} \\
\eta &= (\Sigma_{P_XP_X})^{-1}\mu_{P_X} \frac{J_r}{J_{rr}r} \\
&\quad +(\Sigma_{P_XP_X})^{-1}\Sigma_{P_XX}\delta + (\Sigma_{P_XP_X})^{-1}\Sigma_{P_XC_X}\theta + (\Sigma_{P_XP_X})^{-1}\Sigma_{P_XZ}I'_Z J_{rZ}\frac{1}{J_{rr}r}
\end{aligned} \tag{25}$$

The three asset types - the underlying asset, the call and the put - have a comparable portfolio structure. For each of them, four components form the optimal investment strategy: the preference-dependent speculative fund, two preference-independent hedge funds against variations of the two remaining portfolio asset types and a preference-dependent state variable hedge fund. The main difference between the portfolio solutions for each asset type results from taking into account the characteristics of the given asset class: μ_X, Σ_{XX} and Σ_{XZ} for the underlying asset proportion, μ_{C_X}, $\Sigma_{C_XC_X}$ and Σ_{C_XZ} for the call proportion, μ_{P_X}, $\Sigma_{P_XP_X}$ and Σ_{P_XZ} for the put proportion. One also observes that the signs of the η proportion are almost all opposite to the ones characteristic of the δ and θ proportions, which is a natural consequence of subtracting the puts in the r definition.

When compared with the solution structure in the "symmetric reaction function case" developed in the previous section, one notices the emergence of the two preference-independent hedge funds against the variations of the two other asset classes.

The empirical estimates of the Fed's interest rate rule showed an asymmetric response to inflation and stock market deviations; more precisely, data emphasize a kind of overreaction by the central bank to positive inflation deviations and to negative stock market deviations, while underreaction characterized the opposite changes in these variables. These empirical properties are consistent with our theoretical solution here-above if θ_P largely exceeds η_P, while θ_S is largely lower than η_S. Very probably, the main culprit for such a dynamics is the speculative fund, since it is likely to represent the predominant part of the optimal investment strategy. More precisely, it is probably the value of J_r, which itself is determined by the characteristics of the policymaker's utility function, that is at the origin of this form of asymmetric central bank reaction. One could surmise that the Fed shows a higher aversion to inflation deviation increases and to stock market deviation decreases than to opposite economic evolutions. As a consequence, the central bank utility loss will be higher in the first case than in the second one. This entails overreacting when inflation rises above the targeted level or the stock market index decreases below the fundamental value, while underreaction occurs in the case of inflation deviation decreases or stock market deviation increases.

To conclude our analysis, the Fed's asymmetric reaction to positive/negative key variable variations is probably the consequence of asymmetric central bank preferences.

5 Conclusion

In this paper, we argued that the "Greenspan put" or the provision of liquidity by the Fed in periods of financial turmoil is more a substantive phenomenon than the Fed officials do generally admit. Our empirical analyses show that over a long period, the Fed would reduce the short-term interest rate by 1.5 percentage point if the stock market declines by 10%, while it would not rise an eyebrow when the stock market index goes up. The Fed also seems to react stronger to positive inflation deviations than to negative inflation deviations from trend. We provide an original theoretical modelling of this behavior, building on the portfolio manager problem analyzed and solved by Merton (1971). Our theoretical model defines the optimal monetary policy rule in two settings. Firstly, we extend the analysis of Romaniuk (2008) by including financial stability as a central bank objective. We put forward a time-varying optimal decision rule that brings into the picture expectations, variances and covariances of the key variables. The incorporation of the financial market stability term in the reaction function can be justified from a financial management point of view if it allows to enhance portfolio diversification. The rule was then generalized to allow for asymmetric responses with respect to positive/negative key variable variations in the conduct of monetary policy, by including option terms in the reaction function. The resulting optimal decision rule is more complex, but the optimal portfolio structure remains essentially unchanged.

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