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Stock Market Dynamics and the Central Bank in a General Equilibrium Model

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Abstract

We introduce a general equilibrium model with potentially inefficient stock markets consisting of asymmetrically informed investors. Prices are sticky in the goods market, but the labor market adjusts perfectly. The central bank aims to maximize the life-time wealth of the households in every period by keeping inflation in the steady state and stock markets in the fair value by adjusting the rate of return on risk-free investments. We find that the "leaning against the wind" policy works, which means that positive stock market bubbles can be eliminated by raising the risk-free rate.

JEL Classification: E44, E52, G11

Keywords: Interest Rate, Monetary Policy, Portfolio Choice

1 Introduction

Bean (2004), Roubini (2006) and Yellen (2010) argue that the central bank should intervene in the stock markets to prevent bubbles. On the other hand, Bernanke and Gertler (2001), Greenspan (2004) and Posen (2006) suggest that the central bank should focus on inflation targeting and stable growth in real economy and leave the stock markets monitoring for investors.

Conlon (2015) argues that the central bank should intervene in the stock markets if it has private information about the bubble, whereas an intervention might make things even worse without such information. Taylor (2014) argues that unusually low U.S. interest rate in the 2000s is the key factor in the housing boom and financial crisis afterwards. However, Gali (2014; 2016) argue that the central bank should tackle a positive bubble by lowering the risk-free rate. This is because the bubble component does not have the discounting component, but the bubble develops at the rate of interest rate.

Samuelson (1973) shows that the equilibrium stock price (P_t) is equal to the expected discounted dividends to the shareholder, that is the fundamental value (V_t). According to standard financial theory (Tobin 1958, Sharpe 1964)), investors allocate their investments between risk-free and risky assets. If the risk-free rate is low/high then investors shift their wealth to/from the risky assets. This suggests that if the stock markets equilibrium price (P_t) is above its fundamental value (V_t), the central bank should lift the risk-free rate to nudge investors to shift their asset from risky to risk-free asset. This is the so called “leaning against the wind” policy.

However, according to Gali, leaning against the wind does not work, at least when investors agree with the bubble component, because it does not have a discounting factor in its pricing. This is an important note because, in the (2014) Gali model, market participants are aware of the bubble and include it in their rational expectations. Thus, the bubble inflates with the risk-free rate. Note that there are other meanings to the leaning against the wind policy in the literature such that Svensson (2016), where the central bank is targeting higher interest rate than what is justified by inflation targeting without taking any effect on financial markets bubbles into account.

Inspired by striking result of Gali (2014) and by the conclusions of Conlon (2015), we investigate whether the central bank should or not intervene in the stock market with private information about the bubble. We construct a general equilibrium closed economy model with sticky prices in the goods market and flexible wages in the labor market. In Gali (2014) all investors notice the bubble, but we construct an economy with asymmetric information among investors. That is μ of the investors recognize the real value of the risky asset V_t, and $1-\mu$ estimate in from past values.

The central bank aims to maximize the aggregate real incomes of the households knowing that infinite bubbles are impossible. Thus, the bank targets on constant inflation rate Π, and aims to stabilize all bubbles in the aggregate stock markets. We also assume that the central bank observes V_t, and knows that an infinite bubble is impossible. In addition, we have a common, exogenous and non-stationary technology component in the production function that makes dividends, consumption, and the production itself non-stationary in the general equilibrium. This constitutes permanent shocks into the general equilibrium.

The key issue is the possibility of bubbles, defined by $P_t \neq V_t$. Tirole (1982) shows that $P_t = V_t$ in the rational expectations equilibrium with long-lived risk averse investors so that infinite bubbles are impossible, while Tirole (1985) argues that, in an overlapping generations model with short lived investors and infinitely lived assets bubbles are possible so that $P_t \neq V_t$ may occasionally happen, because the bubbly economy can be passed on to the future generations. However, Santos & Woodward (1997) indicates that bubbles are impossible in rational markets only in the long run, but that there is a possibility of $P_t \neq V_t$ in the short run.

We find that the best policy for the central bank is to aim for steady state inflation and to reduce positive/negative bubbles in the stock markets by lifting/reducing the nominal risk-free rate. That is we prove the optimality of the leaning against the wind policy, when the risk averse households have asymmetric information about the value of the aggregate risky asset, the central bank observes the true value of the asset, the technology component of the firms follows a non-stationary process, and the households have a short investing horizon. Section 2 defines the model, the equilibrium conditions, and the analysis of best monetary policy and section 3 concludes.

2 The Model

The model extends the stock market model of Ilomäki and Laurila (2017) to a closed general equilibrium model with reference to Gali (2014). In the model, there is an infinite set of atomistic households that live for two periods, investing and working in period one, and consuming in period two. In their investment decisions, the households act as constant absolute risk-averse (CARA) investors.

There is a set of infinitely lived firms, whose shares constitute the aggregate of risky assets in the economy. The risk-free alternative yields the nominal rate r_t^{fn}, which is determined by the central bank. The central bank targets on a constant inflation rate Π, and aims also to prevent all bubbles in the aggregate stock markets. The initial wealth of the households is w_t^y. In the model, the portfolio choice is simplified, because the assumption of two-period lived CARA investors omits the possibility of hedging against changes in expected returns, and because the assumption of an infinitely lived risky asset constitutes limits for arbitrage in the overlapping generations model (Shleifer and Vishny, 1997).

The households have asymmetric information about the aggregate dividends in the stock market so that 0< μ <1 of them are informed about future aggregate dividend D_{t+1}, and $1-\mu$ of them are uninformed in every period. The source of the dividends is the following. Each monopolistic firm produces a differentiated good,

$$Y_t(i) = G_t N_t(i) \tag{1}$$

where $Y_t(i)$ is the output of firm i, and $N_t(i)$ is the labor input of firm i, where $i \in [0,1]$. G_t represents the identical (for all firms) technology that evolves exogenously over time. The natural logarithm of G_t follows random walk,

$$\ln G_t = \ln G_{t-1} + e_t^G, \tag{2}$$

where $e_t^G \sim WN(0, \sigma_d^2)$. Each firm sets its price for its good in order to maximize profits subject to the demand constraint

$$Y_t(i) = \left(\frac{p_t(i)}{p_t} \right)^{-e} C_t . \quad (3)$$

We assume that the net profits, $\lambda_t(i) = Y_t(i) - \delta_t(i)$, where δ denotes the firm's production costs, are paid out as dividend D_t. Equation (2) being non-stationary (integrated in order one so that $I(1)$) means that the change in D_t is permanent. This is because the non-stationary component in Equation (1) makes $Y_t(i)$ non-stationary in time. Since $G_t \sim I(1)$, $Y_t(i) \sim I(1)$. This indicates that the change of the net profits $\Delta\lambda_t(i)$ is a martingale difference with $E_{t-1}(\Delta\lambda_t(i)) = 0$.

The history of equilibrium prices, the risk-free rate r_t^{fn} and the current aggregate dividend D_t are common information to all households, but the young informed households have private information about D_{t+1}. This is reasoned by private connections to the firms, which makes their knowledge about the performance of the firms superior compared to the uninformed ones.

For simplicity, the excess returns for the aggregate risky asset are assumed normally distributed, short selling is available to young households, and there are no transaction costs. Note that the assumption of normally distributed excess returns implies constant conditional variance in the risk premium of investors.

Young households sell their labor inelastically against wage W_t. Households use all their assets in the consumption of goods in the second period:

$$C_{t+1} \equiv \left(\int_0^1 C_{t+1}(i)^{1-\frac{1}{e}} di \right)^{\frac{e}{1-e}} \qquad (4)$$

Identity (4) indicates that there is a continuum of differentiated goods available for old households to consume, each produced by a different firm. e denotes constant elasticity of substitution (assumedly $e > 1$), and goods are indexed by $i \in [0,1]$. Thus, the aggregate price index in every period reads

$$p_t \equiv \left(\int_0^1 p_t(i)^{1-e} di \right)^{\frac{1}{1-e}}.$$

We define the gross real risk-free rate as

$$1 + r_t^r \equiv (1 + r_t^{fn}) E_t \left[\frac{p_t}{p_{t+1}} \right],$$

which indicates that the net nominal risk-free rate is

$$r_t^{fn} = \left((1 + r_t^r) E_t \left[\frac{p_{t+1}}{p_t} \right] \right) - 1.$$

2.1 Stock market equilibrium

The market clearing condition for the risky asset reads $\int_y x_y - \int_o s_o = 0$, where x_y refers to total demand of the stock by young investors, and s_o is the total supply of the stock by old investors.

The optimal demand decisions produce the equilibrium price in period *t* thus fulfilling the market clearing condition. This happens because the old investors have to close their position to consume in the second period. In addition, the market clearing condition indicates that the demand per share equals unity in the equilibrium.

A young investor maximizes his/her utility from period 2 consumption by maximizing life-time incomes, that is by optimizing on the investments in the financial markets. The maximization problem reads

$$
\begin{aligned}
& Max[E(-e^{-vc_{t+1}} \mid \theta_t^y, w_t^y)] \\
& s.t. \\
& c_{t+1} = x^f (1 + r_t^{fn}) + x^r E_t(R_{t+1}) \\
& w_t^y = x^f + x^r
\end{aligned}
\qquad (5)
$$

where θ_t^y is the information set, $v > 0$ is the coefficient of risk aversion, c_{t+1} is consumption when old, w_t^y is the amount of initial wealth, and x^f and x^r denote the amount of money invested in risk-free and risky assets, respectively. The net excess return on a risky share is

$$R_{t+1} \equiv \frac{P_{t+1} - P_t + D_{t+1}}{P_t} - r_t^{fn}. \qquad (6)$$

Assuming normally distributed extra consumption, taking expectations in Equation (6) and plugging the consumption constraint into the utility function yields

$$E_t\left[U(c_{t+1})\right] = -e^{-vx^r E_t(R_{t+1}) + \frac{v^2}{2} x^{r^2} \sigma_r^2}, \qquad (7)$$

where σ_r^2 is the variance of excess returns. However, since informed investors have better information about risky assets, it must be that $\sigma_{ri}^2 < \sigma_{ru}^2$. Note that, since the investors observe r_t^{fn}, its variance is zero. Maximizing (7) with respect to x^r, using Equation (6) and noting that the demand per risky asset's share is one in the equilibrium, the first order condition reads

$$\frac{E_t\left[\frac{P_{t+1} - P_t + D_{t+1}}{P_t}\right] - r_t^{fn}}{\nu\sigma_r^2} = 1, \tag{8}$$

where

$$E_t\left[\frac{P_{t+1} - P_t + D_{t+1}}{P_t}\right] - r_t^{fn} = \nu\sigma_r^2 = \omega. \tag{9}$$

denotes the risk premium. Manipulation of Equation (8) yields

$$P_t = \frac{E_t\left[P_{t+1} + D_{t+1}\right]}{\left(1 + r_t^{fn} + \nu\sigma_r^2\right)} \tag{10}$$

for the pricing rule of the risky asset. After solving Equation (10) forward for k periods, we have

$$P_t = E_t\left[\sum_{s=1}^{k} \frac{D_{t+s}}{(1 + r_t^{fn} + \nu\sigma_r^2)^s}\right] + E_t\left[\frac{P_{t+k}}{(1 + r_t^{fn} + \nu\sigma_r^2)^k}\right],$$

from which the second term on the right hand side shrinks to zero as the horizon k increases, indicating that

$$\lim_{k\to\infty} E_t\left[\frac{P_{t+k}}{\left(1+r_t^{fn}+\nu\sigma_r^2\right)^k}\right]=0,$$

which means that

$$P_t = E_t\left[\sum_{s=1}^{\infty}\frac{D_{t+s}}{(1+r_t^{fn}+\nu\sigma_r^2)^s}\right]. \tag{11}$$

Recalling the properties of random walk, the change in the dividend at time t is permanent, and the rational choice represented by Equation (11) results over time in the perpetuity model,

$$P_t = \frac{D_{t+1}}{(r_t^{fn}+\nu\sigma_{ri}^2)} = V_t, \tag{12}$$

where σ_{ri}^2 is the variance of the informed investors' excess returns. Therefore, it can be concluded that Equation (12) reflects the fundamental value of the risky asset, and that the pricing pattern of the informed investors follows it.

In any period t, the uninformed investors observe the current dividend D_t and the risk-free rate. Hence, the rational choice of the uniformed investors gives

$$P_t = \frac{D_t}{(r_t^{fn}+\nu\sigma_{ru}^2)}, \tag{13}$$

where σ_{ru}^2 is the variance of the uninformed investors' excess returns. Using equations (12) and (13), and recalling that μ is the share of the informed households and $1\text{-}\mu$ is the share of the uninformed households, the aggregate pricing rule for the risky asset in the financial market reads

$$P_t = \mu \frac{D_{t+1}}{r_t^{fn} + v\sigma_{ri}^2} + (1-\mu)\frac{D_t}{r_t^{fn} + v\sigma_{ru}^2}. \tag{14}$$

The market price given by equation (14) results from the asymmetry of information among the investors.

Proposition: *If the risk-free rate rises/falls, the equilibrium price reduces/increases, ceteris paribus.*

Proof: Differentiate Equation (14) against P_t and r_t^{fn}, manipulate, and get

$$\frac{\partial P_t}{\partial r_t^{fn}} = -\mu \frac{D_{t+1}}{(r_t^{fn} + v\sigma_{ri}^2)^2} - (1-\mu)\frac{D_t}{(r_t^{fn} + v\sigma_{ru}^2)^2} < 0. \tag{15}$$

The effect is clearly negative, since both terms on the right-hand side are negative, Equation (15) shows that, if the risk-free rate rises/falls, the equilibrium aggregate stock price falls/rises thus eliminating the bubble. ***Q.E.D.***

Next, consider an alternative case, where the uninformed households operate as technical traders and price their offers according to past prices. Manipulating Equation (8), and taking one step backwards in prices and in dividend yields produces

$$P_t^u = (1 + r_t^{fn} + \nu\sigma_{ru}^2)P_{t-1} - D_t \,. \tag{16}$$

Using Equations (12) and (16), the aggregate pricing rule in the financial market reads

$$P_t = \mu V_t + (1-\mu)\left[(1 + r_t^{fn} + \nu\sigma_{ru}^2)P_{t-1} - D_t\right]. \tag{17}$$

Corollary: *If the uninformed investors operate as technical traders, the basic result remains the same.*

Proof: Differentiate Equation (17) against P_t and r_t^{fn}, manipulate, and get

$$\frac{\partial P_t}{\partial r_t^{fn}} = -\mu \frac{D_{t+1}}{(r_t^{fn} + \nu\sigma_{ri}^2)^2} + (1-\mu)P_{t-1} \,.$$

The effect is negative if $\frac{\mu D_{t+1}}{(1-\mu)P_{t-1}} > \left(r_t^{fn} + \nu\sigma_{ri}^2\right)^2$, which says that the equilibrium price falls if the weighted dividend return is larger than the squared net required return of informed investors. The condition is reasonable in general, but it adds in defining the regime, where the leaning against the wind policy works. However, that the uninformed investors operate as technical traders means that there is a possibility of rapidly growing bubble conditions, because the discounting factor is absent in Equation (16). ***Q.E.D.***

2.2 Goods and labor markets equilibrium

Each firm produces a differentiated good and the monopolistic firm operates under Equation (1). Each firm sets its price to the good in order to maximize its share value subject to Equation (3). In addition, we assume nominal rigidities such that the price of each good is set in advance. That is, the selling price of a good in period t, that is p_t^*, is set in the period $t-1$ subject to Equation (3). Then, the optimal price-setting rule for the firms is

$$E_{t-1}\left\{Y_t\left(\frac{p_t^*}{p_t}-\mathrm{M}W_t\right)\right\}=0 \ , \tag{18}$$

where $\mathrm{M}\equiv\frac{e}{e-1}$. However, if the goods prices were perfectly flexible, then $p_t^*=\mathrm{M}p_tW_t$, where M is a constant gross mark-up, and p_tW_t is the nominal marginal cost.

Each good market clears when $Y_t(i)=C_t(i)$ for all $i\in[0,1]$ in all periods t. Denoting aggregate output as

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

indicates together with Equation (1) that the aggregate goods market clearing condition reads

$$Y_t=C_t\,. \tag{19}$$

This indicates that the aggregate net profits is $\lambda_t = Y_t - \delta_t = D_t$, where D_t is the aggregate dividend. The labor market clears when

$$\varphi_t = G_t \int_0^1 N(i)di = \int_0^1 Y_t(i)di = Y_t. \tag{20}$$

This indicates that all firms set identical prices and produce same quantities in the symmetric equilibrium. Then, the supply of the aggregate output is equal to φ_t, which is non-stationary because of the assumption of flexible labor supply with non-stationary exogenous technology of Equation (2). Under flexible goods prices, that is if the firms can set the goods price when they observe φ_t, the optimal price setting implies constant real wage

$$W_t = \frac{1}{\mathrm{M}}.$$

Thus, under sticky goods prices at the symmetric equilibrium, optimal price setting can be written as

$$W_t = \frac{1}{\mathrm{M}} + u_t, \tag{21}$$

where u_t is the martingale difference with $E_{t-1}(u_t) = 0$. In addition, from the income side

$$Y_t = w_t^o + W_t, \tag{22}$$

where w_t^o is the aggregate investing wealth of the old households before consuming. Using Equations (21) and (22), the equilibrium production reads

$$Y_t = w_t^o + \frac{1}{\mathrm{M}} + u_t \, , \tag{23}$$

which is a martingale process with drift $\left(\frac{1}{\mathrm{M}}\right)$ in the optimum price setting. Then using Equations (19), (20) and (23) we have a general equilibrium

$$\varphi_t = C_t = w_t^o + \frac{1}{\mathrm{M}} + u_t = Y_t \tag{24}$$

indicating that all main variables in the equilibrium except the real wage are non-stationary. In addition, there is a martingale difference $E_{t-1}(u_t) = 0$ that reacts with a lag to $\ln G_t = \ln G_{t-1} + e_t^G$. Whereas under perfectly flexible goods prices we have an equilibrium $Y_t = \varphi_t = C_t = w_t^o + \frac{1}{\mathrm{M}}$. Thus, if the firms could set their prices with the knowledge of e_t^G, the inflation would be at the steady state Π. Hence, the exogenous shock e_t^G creates $\Pi_t \neq \Pi$, because the firms must decide the price of their goods before the shock emerges. In addition, because of asymmetric information in the stock markets, the exogenous shock e_t^G creates bubbles into the risky assets.

2.3 The central bank

Recall that the technology shock follows $\ln G_{t+1} = \ln G_t + e^G_{t+1}$, where $e^G_t \sim WN(0, \sigma^2_G)$, that the non-stationary aggregate net profits $\lambda_t = Y_t - \delta_t$ are paid out as the aggregate dividend D_t .Then it is obvious that the conditional expected dividend $E_t(D_{t+1}) = D_t$ is not equal to the realized D_{t+1}. However, we assume that informed investors and the central bank have private information about future performance of aggregate firms such that they are able to observe D_{t+1} in advance. Hence, Equation (12), $V_t = \frac{D_{t+1}}{r_t^{fn} + \nu\sigma^2_{ri}} = \Gamma_t$, represents the fundamental value of the aggregate firms, and Equation (14), $P_t = \mu \frac{D_{t+1}}{r_t^{fn} + \nu\sigma^2_{ri}} + (1-\mu)\frac{D_t}{r_t^{fn} + \nu\sigma^2_{ru}} = \Omega_t$, gives the equilibrium price. The central bank aims to maximize the aggregate utility of all households. Therefore, the task of the central bank is to eliminate any bubbles in the financial market by using monetary policy to adjust the risk-free rate of return.

The central bank sets the nominal risk-free rate r_t^{fn} according to the rule

$$1 + r_t^{fn} = (1 + r_t^r) E_t[\Pi_{t+1}] \left(\frac{\Pi_t}{\Pi}\right)^{\lambda_\Pi} \left(\frac{\Omega_t}{\Gamma_t}\right)^{\lambda_A}, \tag{25}$$

where $\Pi_t \equiv \frac{p_t}{p_{t-1}}$ denotes gross inflation, Π is the inflation target, and $(1 + r_t^r)$ is the gross real risk-free rate. This rule assures that the real interest rate reacts to the changes in inflation with strength $\lambda_\Pi > 0$. In Equation (25), $\frac{\Omega_t}{\Gamma_t} > 1$ refers to a positive bubble in the stock market. The proof of Proposition assures that $\lambda_A > 0$ in Equation (25). Thus, a rise in the nominal risk-free rate deinflates the stock market bubble.

In the alternative case of the uninformed investors acting as technical traders, the last component in Equation (25) is $\frac{\gamma_t}{\Gamma_t}$, where $P_t = \mu V_t + (1-\mu)\left[(1 + r_t^{fn} + \nu\sigma_{ru}^2)P_{t-1} - D_t\right] = \gamma_t$.

Then $\frac{\gamma_t}{\Gamma_t} > 1$ refers to a positive bubble in the stock market. The proof of Corollary assures that $\lambda_A > 0$ in Equation (25) within the reasonable regime $\frac{\mu D_{t+1}}{(1-\mu)P_{t-1}} > \left(r_t^{fn} + \nu\sigma_{ri}^2\right)^2$.

The goal of the central bank is to maximize households' welfare in each period. It is clear that asymmetric information about the fundamental value of the stock market among households is the key issue concerning the welfare of the aggregate households. Because informed households are able to calculate the non-bubble stock market price they make right investing decisions. Hence, the uninformed households tend to make mistakes in their investing decisions resulting larger variance in their consumption when they are old compared to the informed households' variance. Thus, the goal of the central bank is to minimize the difference of variances between informed and uninformed households by following Equation (25) with $\lambda_A > 0$.

3 Conclusions

The paper presents a general equilibrium model where the central bank knows that infinite bubbles in the stock markets are impossible, and where one proportion of households observes the real value of the aggregate stock markets while the others are uninformed about it. Furthermore, investing in the financial markets offer the only way to the households to maximize their life-time wealth and thus consumption. Taken that infinite bubbles are impossible, the central bank must stabilize the bubble in order to save uninformed households from suffering from the eventual burst of the bubble. Hence, the goal of the central bank is both to stabilize the stock market bubbles and to keep inflation in the steady state in order to maximize the aggregate life-time real incomes of the households.

We find that that if the risk-free rate rises/falls, the equilibrium price in the stock markets reduces/increases, ceteris paribus. In contrast to Gali (2014), we prove the working of the leaning against the wind policy in the stock markets. It is clear that our results depend on several key assumptions and hence the proof is valid only when they are fulfilled.

First, following Gali (2014), an OLG model is used to facilitate the development of a stock market bubble in the first place. The assumption is reasonable with short investing periods and frequent monitoring of the investors' performance. Second, we assume that only a portion of the risk-averse investors recognizes the true value of the stock market in every period. Thus, there is more room for a bubble to develop, because all investors do not simply observe that the stock markets are overvalued. This differs from the model of Gali, because in his model the bubble is a rational bubble that grows with the risk-free rate. In our set-up, rapid growth of an irrational bubble is possible, if the uninformed investors act as technical traders. This is because the discounting factor is missing in their pricing rule. Third, in contrast to standard macroeconomics equilibrium models, we have a non-stationary production technology that makes every main component non-stationary in the equilibrium as well. Thus, the random walking technology produces permanent changes in the equilibria. And last, we assume that the central bank observes the true value of the aggregate stock market.

The main contribution of the paper is to show that the leaning against the wind policy in the stock markets works, if the risk-averse investors have a short investing period and asymmetric information about the fundamental value of the stock market, if the central bank observes the infinitely impossible bubble, and if the technology of the firms follows a non-stationary process. Moreover, if the uninformed investors act as technical traders, the central bank is urged to prevent super bubble to develop.

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