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RESEARCH ARTICLE

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Leaning against the wind policy and animal spirits in a general equilibrium model

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Abstract

We introduce a general equilibrium model with sticky prices and flexible wages. People live over two periods, investing and working in period 1, and consuming in period 2. In the financial market, some investors are informed about the fundamental stock value, while the rest are not, and trust their gut feeling (animal spirits). The informed investors are risk-averse, and the correlated animal spirits of the uninformed ones affects the stock market equilibrium thus producing an irrational bubble. We find that central bank's leaning against the wind policy is effective in controlling the bubble, if the uninformed investors discount their animal spirits anticipation of future dividends. Moreover, the paper shows that an irrational bubble may have similar effects on stock market prices as a rational bubble.

KEYWORDS

animal spirits, informed investors, interest rate, monetary policy, portfolio choice, uninformed investors

JEL CLASSIFICATION

E43; E44; E52; G4; G11

1 | INTRODUCTION

Should central banks play against stock market bubbles? For example, Bernanke and Gertler (2001) claim that the central bank should affect asset prices by controlling inflation, while Greenspan (2004), and Posen (2006) argue that the central bank should concentrate on inflation targeting and stable growth, but leave stock market adjustment for investors. In fact, Greenspan (2002) argues that the central bank should care only about reducing damages after the eventual burst (so called cleaning up the mess policy). However, letting super bubbles to develop and burst may create huge welfare losses. Taylor (2014) claims that the unusually low U.S. interest rates in early 2000s were among the key triggers of the financial crisis in 2007–2008. Goodhart (2001) offers a simple solution to that problem by including asset prices in inflation calculations.

Bordo and Jeanne (2002), Bean (2004), Roubini (2006), and Yellen (2010) support central bank's interference in the stock markets. The question then is, should stock market overvaluation be tackled with higher or lower risk-free rates of return? Brunnermeier and Schnabel (2016) report that, while central banks have been successful in deflating bubbles in the history, the policy approach remains fraught with difficulties. First, stock market bubbles can be hard to detect with confidence. Second, deflating a bubble by monetary policy may cause a significant drop in real production. And third, since stock market bubbles seem to be linked with financial market instability, they should be tackled rather by financial regulation (Blanchard & Gali, 2007).

By standard financial theory (Sharpe, 1964; Tobin, 1958), risk-averse investors allocate investments between risk-free and risky assets. Samuelson (1973) proves that, with first-order expectations, the equilibrium stock price (P_t) is equal to the expected discounted dividends (D_t), that is the fundamental value (V_t). The so called "leaning against the wind" principle says that if the stock markets are overvalued ($P_t > V_t$) for extended periods, the central bank should lift the risk-free rate to nudge investors to shift their investments from risky to risk-free assets thus correcting the bubble. Maio (2014) supports the view by showing empirically that an increase in the risk-free rate of return makes investors reduce their risky investments.

By Gali (2014, 2016), a risky asset has two components: a fundamental value component and a bubble component. In the (2014) Gali model, all market participants are aware of the bubble and include it in their rational expectations. Thus, the bubble component is rational, since all investors assume that they can pass it to the next generation. That the model develops a rational bubble explains why the bubble inflates further when the risk-free rate rises. The leaning against the wind does not work, because the bubble component does not have a discounting factor in its pricing - otherwise the equilibrium price should fall when the risk-free rate rises (ceteris paribus).

Assumption 1 A rational bubble inflates with the risk-free rate, and all market participants are aware of the bubble and include it in their rational expectations.

Starting from Samuelson (1958) and Tirole (1985), assets bubbles may occasionally exist in an overlapping generations model with short lived investors, because old investors can pass on the bubble for the next generation. The overlapping generations model can be motivated if the majority of investors in the market are professional wealth managers who handle other people's money with performance monitoring in short intervals (Shleifer & Vishny, 1997). Santos and Woodford (1997) show that bubbles are impossible in markets in the long run, but that there is a possibility of $P_t \neq V_t$ for shorter periods. Furthermore, Farhi and Tirole (2012) find that bubbles are possible even when the economy is dynamically efficient, if the demand for liquidity is high, or if the agency problems are severe.

Conlon (2015) notes that asymmetric information produces irrational bubbles. By Martin and Ventura (2012), investors' sentiments produce bubbles because the current size of the bubble depends on market expectations regarding their future size. Information asymmetry together with correlated behaviour of uniformed investors are key components in the models of stock markets frictions. See, DeLong, Shleifer, Summers, and Waldmann (1990), Froot, Scharfstein, and Stein (1992), Campbell and Kyle (1993), Kyle and Xiong (2001), and Cespa and Vives (2015) among others.

Smith, Suchanek, and Williams (1988) define a positive irrational bubble as a situation, where $P_t > V_t$ for extended periods and only a part of investors recognizes it. Shiller (2014) argues that irrational bubbles can emerge, when uninformed investors utilize their gut feeling in correlation with others. That is they trust on their correlated animal spirits. We follow Shiller by assuming that the animal spirits component is the gut feeling of correlated uninformed investors, for example, an irrational overreaction to past technology shocks. The gut feeling is not connected to any fundamental factors that concern the risky asset.

Definition 1 Animal spirits is a correlated gut feeling about the value of a risky asset and not connected to any fundamental factors concerning the asset.

Definition 2 An irrational positive bubble exists in the stock market ($P_t > V_t$ for extended periods), if only informed investors recognize the bubble and uninformed investors utilize animal spirits in their investment decisions thus creating correlated demand for risky assets.

De Grauwe (2011) shows that the animal spirits component can arise in the DSGE-model with the implication that pure inflation targeting by the central bank becomes suboptimal, because it can increase volatility both in output and inflation. Lengnick and Wohltmann (2016) show that animal spirits do not affect the coefficients of optimal Taylor rules, if the central bank cares about financial market stability, too. Ilomäki and Laurila (2018) find experimental evidence on effects of animal spirits component on both informed and uninformed investors' decisions in financial markets. See also Sheen and Wang (2016) about the effect of animal spirits on labour markets.

This paper presents an overlapping generations general equilibrium model of a closed economy to assess the validity of the leaning against the wind policy. In the model, investors have asymmetric information about the fundamental value of the aggregate risky asset, and have a short investing horizon. Uninformed investors utilize their correlated animal spirits. Technology follows a non-stationary process, prices are sticky in the goods market, and wages are flexible in the labour market.

The model extends the stock market model of Ilomäki and Laurila (2017) with reference to Gali (2014), and Shiller (1984, 2014). Then model rests on four main assumptions. First, following Gali (2014), the overlapping generations model facilitates the development of a stock market bubble in the first place. The assumption is reasonable with short investing periods and frequent monitoring of investors' performance. Second, one portion of the investors recognizes the true value of the risky stock in every period that is future dividends D_{t+1}, while the rest rely on their gut feeling. Third, rapid inflation of an irrational bubble is possible, if the uninformed investors use their correlated animal spirits. It can be boosted by, say, some intriguing investing stories that spread rapidly in social media. Fourth, in contrast to standard macro models, we have a non-stationary production technology that makes every main component non-stationary in the equilibrium as well. Thus, the random walk technology produces permanent changes in equilibria indicating that there are periodical breaks over time, and the impacts of technological shocks are observable only afterwards, not forecastable beforehand. This is a realistic assumption, since all major macroeconomic variables are non-stationary in real life. However, we assume that the informed investors are able to monitor the effect of the latest technology shock on the dividends, while the uninformed investors rely on their gut feeling.

The central bank aims to maximize the aggregate real incomes of people knowing that infinite bubbles are impossible. Thus, the bank targets on constant inflation rate Π, and aims to stabilize all bubbles in the stock market by using monetary policy to set the risk-free rate of return for the next period.

In particular, this paper expands the seminal analysis of Shiller (1984, 2014). According to the Shiller model, central bank's operations via the nominal risk-free rate has no effect on the wedge between the equilibrium price P_t and the fundamental value V_t so that they keep drifting apart from each other. This is because ordinary investors do not discount their gut feeling valuation of the risky asset. However, leaning against the wind policy becomes operative, if the uninformed investors also discount their approximation about future dividends against the risk-free rate, and invest all their initial wealth to the asset that offers the highest anticipated returns. This can be reasoned by considering an uninformed investor who is biased but otherwise rational: he realizes that his gut feeling about the asset price impact from a technological innovation must include also a discount factor, since it concerns future cash flows. Thus, a rise in the nominal risk-free rate reduces the wedge between P_t and V_t in the case of a positive irrational bubble even though the gut feeling would exaggerate the impact of the innovation.

The paper proceeds as follows. Section 2 defines the basic model, and Section 3 constructs the market equilibrium. Section 4 analyzes central bank policy, and Section 5 concludes.

2 | THE BASIC MODEL

2.1 | The household sector

There is a set of households [0, 1] that live for two periods, investing and working in period one, and consuming in period two. When old, people optimize on the allocation of their consumption expenditures, $C_t \equiv \left(\int_0^1 C_t(i)^{1-\frac{1}{\varepsilon}} di\right)^{\frac{\varepsilon}{\varepsilon-1}}$, saying that there is a continuum of differentiated goods available for old households to consume, each produced by a different firm $i \in [0, 1]$ and where $\varepsilon > 1$ denotes constant elasticity of substitution. Thus, they solve

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

s.t.

$$\int_0^1 p_t(i) C_t(i) di \equiv Z_t, \tag{1}$$

where Z_t is the accumulated wealth that covers the consumption expenditures and p_t is the price of the good i. The optimization yields, after manipulation,

$$C_t(i) = \left(\frac{p_t(i)}{p_t}\right)^{-\varepsilon} C_t, \tag{2}$$

where C_t is the aggregate consumption of the old households at period t, and the aggregate price index in every period is $p_t \equiv \left(\int_0^1 p_t(i)^{1-\varepsilon} di\right)^{\frac{1}{1-\varepsilon}}$.

2.2 | The firm sector

There is a set of infinitely lived firms [0, 1], that maximize net profits by setting the price of their products. Each monopolistic firm produces a differentiated good,

$$Y_t(i) = G_{t-1} N_t(i), \tag{3}$$

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

$$\ln G_t = \ln G_{t-1} + \xi_t^G,$$

where $\xi_t^G \sim WN\left(0, \sigma_G^2\right)$.

Each firm sets its price for its good in order to maximize profits subject to the demand constraint (2), and each good market clears when $Y_t(i) = C_t(i)$ in all periods t. 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, p_t^*, is set in period $t-1$. The maximization problem for the firms reads

$$\underset{p_t*}{Max} E_{t-1}\left\{ Y_t \left(\frac{p_t^*}{p_t} - W_t \right) \right\}$$
$$s.t.$$
$$Y_t(i) = \left(\frac{p_t^*}{p_t} \right)^{-\varepsilon} C_t,$$

where E is the expectations operator. Young households sell their labour inelastically against production adjusted real wage W_t. Solving the firms' maximization problem produces the first order condition

$$E_{t-1}\left\{ Y_t \left(\frac{p_t^*}{p_t} - \mathrm{M} W_t \right) \right\} = 0, \tag{4}$$

where $\mathrm{M} \equiv \frac{\varepsilon}{\varepsilon - 1}$. If goods prices were perfectly flexible, $p_t^* = \mathrm{M} p_t W_t$, where M is a constant gross mark-up, and $p_t W_t$ is the nominal marginal cost. The net profits are paid out as dividendsD_t. Since $\ln G_t = \ln G_{t-1} + \xi_t^G$ implies non-stationarity, the change in D_t is permanent. This is because also $Y_t(i)$ must be non-stationary in time. Since $G_t \sim I(1)$, $Y_t(i) \sim I(1)$, change in dividends is a martingale difference with $E_{t-1}(\Delta D_t(i)) = 0$.

3 | THE GENERAL EQUILIBRIUM

3.1 | Stock market equilibrium

For simplicity, the excess returns for the aggregate risky asset are assumed normally distributed, short selling is available to young investors, and there are no transaction costs. Note that the assumption of normally distributed excess returns implies constant conditional variance in the risk premium. We define the gross real risk-free rate as $1 + r_t^r \equiv \left(1 + r_t^{fn}\right) E_t\left[\frac{p_t}{p_{t+1}}\right]$, which says that the net nominal risk-free rate is $r_t^{fn} = \left(\left(1 + r_t^r\right) E_t\left[\frac{p_{t+1}}{p_t}\right]\right) - 1$.

The history of equilibrium prices, the risk-free rate r_t^{fn} and the current aggregate dividend D_t are common information to all young investors. The informed investors recognize the effect of G_t on the profitability of the firms, which results in private information about the aggregate dividend D_{t+1}. Thus, there is asymmetric information: some investors are informed about future aggregate dividend D_{t+1}, while the rest are uninformed of that in every period. This is reasoned by private connections to the firms, which makes the informed investors' knowledge about the firms' performance superior compared to the uninformed ones. In their investment decisions, the informed investors are risk-averse, and the uninformed ones utilize their gut feeling in correlation with others in their investment decisions, thus trusting on their correlated animal spirits. The initial wealth of all investors is w_t^y.

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 the old ones. The 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 in order to consume in the second period. In addition, the market clearing condition indicates that the demand per share equals unity in the equilibrium. The total demand of informed and uninformed investors reads

$$x_t^{ri} + \frac{x_t^{ru}}{P_t} = 1, \tag{5}$$

where x^{ri} is the demand of the informed investors per share, and x^{ru}/P_t is the demand of the uninformed investors per share (Shiller, 1984, p. 478).

The young investors maximize their utility from period 2 consumption by maximizing lifetime incomes. Since labour supply is fixed, they optimize only on investments in the financial markets. The young informed investors' maximization problem reads

$$Max\left[E\left(-e^{-\nu C_{t+1}} | \theta_t^y, w_t^y\right)\right]$$
$$s.t.$$
$$C_{t+1} = x^f\left(1 + r_t^{fn}\right) + x^r(r_{t+1})$$
$$w_t^y = x^f + x^r$$

where θ_t^y is the information set, $\nu > 0$ is the coefficient of risk aversion (CARA), 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. Assuming normally distributed extra consumption, and taking expectations yields $E_t[U(c_{t+1})] = -e^{-\nu x^r E_t(r_{t+1}) + \frac{\nu^2}{2} x^{r^2} \sigma_r^2}$, where σ_r^2 is the variance of excess returns. Note that the investors observe r_t^{fn}, since the central bank announces the risk-free rate in the previous period. Thus, its variance is zero, and in that rate the demand per share of the informed investors is zero, $x^{ri} = 0$. Maximization with respect to x^{ri} results in the demand of the informed investors per share,

$$x_t^{ri} = \frac{E_t(r_{t+1}) - r_t^{fn}}{\omega_i}, \tag{6}$$

where $\omega_i = \nu\sigma_r^2$ is the constant risk premium of the informed investors. Plugging the definition $r_{t+1} \equiv \frac{P_{t+1}+D_{t+1}}{P_t} - 1$ into Equation (6) and manipulating (see Appendix A) we eventually get the perpetuity valuation price for the risky asset:

$$P_t = \frac{D_{t+1} + \omega_i x_t^{ru}}{r_t^{fn} + \omega_i}. \tag{7}$$

Proposition 1 Leaning against the wind policy does not work, if the uninformed investors with animal spirits do not discount their anticipation on forthcoming dividends.

Proof: Take total derivate from Equation (7) with respect to r_t^{fn}. Note that the dividend stream is an exogenous process, and the risk premium of the informed investors is constant. Then,

$$\frac{dP_t}{dr_t^{fn}} = \frac{P_t}{\left(r_t^{fn} + \omega_i\right)} + \frac{-\left(D_{t+1} + \omega_i x_t^{ru}\right)}{\left(r_t^{fn} + \omega_i\right)^2} = 0. \tag{8}$$

This is the basic result proposed by Shiller (1984), implying that leaning against the wind policy is not effective. ***Q.E.D.***

Figure 1 below illustrates the Shiller case of Equation (7), where the uninformed investors with animal spirits do not discount their anticipation on forthcoming dividends.

In Figure 1, the horizontal axles present the uninformed investors' relative overvaluation in percentages, and the vertical axles present the uninformed investors' demand between 0 and 1 per share. The upper graph shows the relative overvaluation with 1% nominal risk-free rate, and the lower graph shows the relative overvaluation with 10% nominal risk-free rate. The graphs being practically identical demonstrates that the level of the risk-free rate is irrelevant to the wedge (that is spread) between P_t and V_t. Only the demand of risky asset per share has effects on the wedge (ceteris paribus). The linear relationship reflects the effect of animal spirits on the asset bubble.

However, we claim that it would be reasonable to assume that the uninformed investors also pay attention

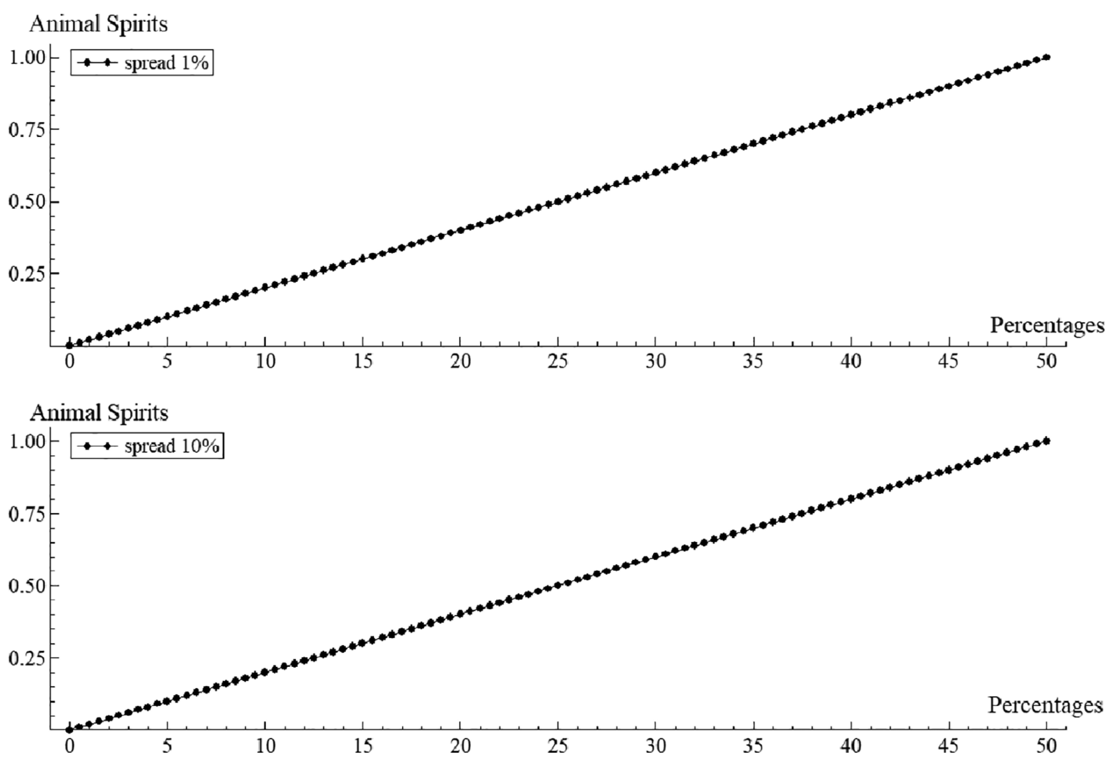

FIGURE 1 Animal spirits without discounting

to the opportunity cost of the risky investments in order to determine, which of the two options they take. This is to say that they should discount future stock returns against the risk-free rate, even if they are risk neutral, and whatever their anticipations of the forthcoming dividends are.

Proposition 2 In the presence of correlated animal spirits, leaning against the wind policy works, if the uninformed investors with animal spirits are risk-neutral, and discount their anticipated future dividends.

Proof: Assume that the uninformed investors are risk-neutral ($\omega_u = 0$), and discount their animal spirits excess anticipation of D_{t+1}, denoted by α_{t+1}. Thus, the animal spirits anticipation α_{t+1} is the estimation error of D_{t+1} compared to the informed investors' estimation. Since they are risk-neutral, they invest all their wealth to the stock market, if it offers the highest expected returns, based on their gut feeling about D_{t+1}. This produces (see Appendix B):

$$P_t = \frac{D_{t+1} + \omega_i \alpha_{t+1} / r_t^{fn}}{r_t^{fn} + \omega_i}, \tag{9}$$

where the demand of uninformed investors $\left(x_t^{ru}\right)$ is fixed. Take total derivate on Equation (9) with respect to r_t^{fn}, recalling that $E_t(\Delta\alpha_{t+1}) = 0$, and get

$$\frac{dP_t}{dr_t^{fn}} = -\frac{1}{\left(r_t^{fn} + \omega_i\right)^2}\left[D_{t+1} + \frac{\left(2r_t^{fn} + \omega_i\right)\omega_i \alpha_{t+1}}{r_t^{fn^2}}\right] < 0. \tag{10}$$

The result (10) says that the leaning against the wind policy is effective in controlling irrational bubbles. ***Q. E.D.***

Figure 2 below illustrates the case, where the uninformed investors discount their anticipated cash flows from the dividends in their fixed state of demand.

In Figure 2, overvaluation of the risky asset in percentages is presented on the vertical axis, and the considered nominal risk-free rates are presented on the horizontal axis. The graph is drawn so that the risk-neutral uninformed investors with their correlated animal spirits overestimate D_{t+1} by 10% and the risk premium of the informed investors is 5%. Thus, the graph illustrates the wedge (in percentages) between the equilibrium price P_t and the fundamental value V_t. When the nominal risk-free rate is 1%, the relative market overvaluation of the risky asset is 50%, and if the central bank lifts the risk-free rate, say, to 5%, the overvaluation shrinks to 10%. Overall, the shape of the reduction pace does not depend on the informed investors' risk premium, or on the rate of dividend's D_{t+1} relative overestimation. Thus, the simple formulation in Equation (9) seems to produce results that resemble the idea of the famous Zipf's law.

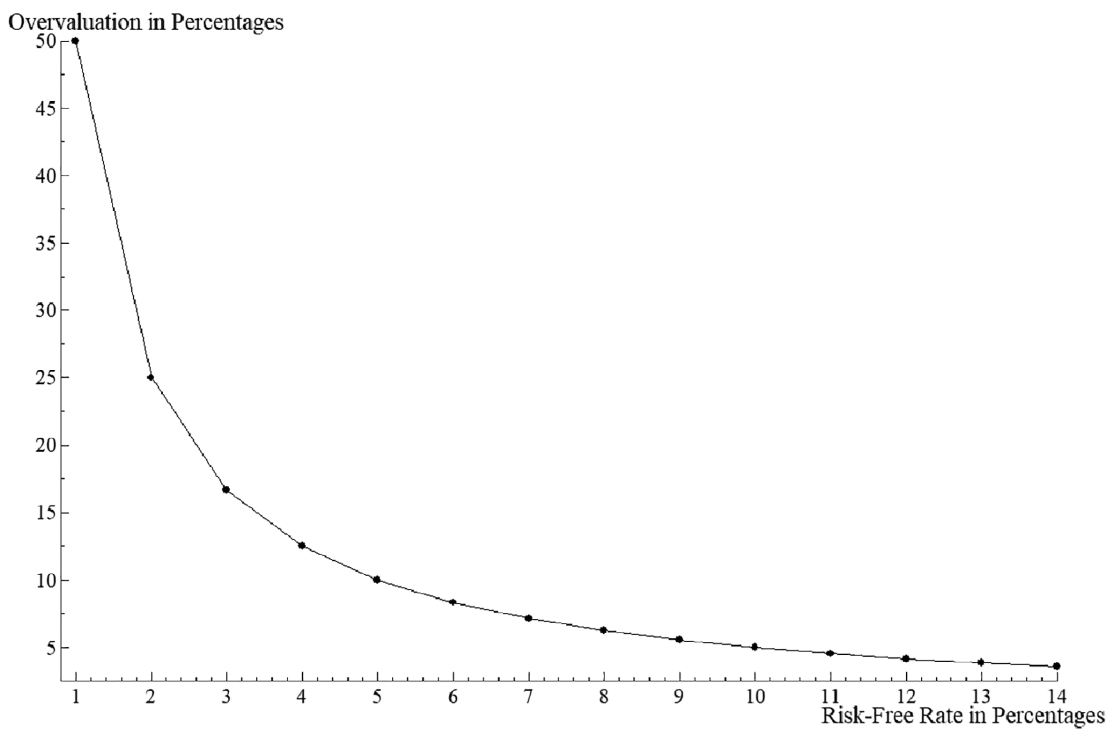

FIGURE 2 Animal spirits with discounting, $\alpha_{t+1} = 10\%$ and $\omega_i = 5\%$

3.2 | Goods and labour market equilibria

Each monopolistic firm sets its price in advance so that the selling price of a good in period t, p_t^*, is set in the period $t-1$ subject to Equation (4). Denoting aggregate output as

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

indicates together with Equation (2) that the aggregate goods market clearing condition reads

$$Y_t = C_t. \quad (11)$$

The labour market clears when

$$\phi_t = G_{t-1} \int_0^1 N(i)di = \int_0^1 Y_t(i)di = Y_t. \quad (12)$$

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 labour supply with non-stationary and exogenous technology. If goods prices were flexible, that is if firms could their prices upon ϕ_t, $\frac{p_t^*}{p_t} = 1$, and $W_t = \frac{1}{\mathrm{M}}$. Under sticky goods prices at the symmetric equilibrium, optimal price setting reads $W_t = \frac{1}{\mathrm{M}} + u_t$, where u_t is the martingale difference with $E_{t-1}(u_t) = 0$. In addition, from the income side $Y_t = w_t^o + W_t = Z_t$, where w_t^o is the aggregate investing wealth of old people and Z_t is the accumulated wealth before consuming. Then, equilibrium production is

$$Y_t = w_t^o + \frac{1}{\mathrm{M}} + u_t = Z_t \quad (13)$$

which is a non-stationary process with drift $\left(\frac{1}{\mathrm{M}}\right)$ in the optimum price setting. The general equilibrium reads

$$\phi_t = C_t = w_t^o + \frac{1}{\mathrm{M}} + u_t = Y_t = Z_t. \quad (14)$$

Note, that there is a martingale difference $E_{t-1}(u_t) = 0$ that reacts with a lag to $\ln G_t = \ln G_{t-1} + \xi_t^G$. Under flexible goods prices, the equilibrium would read $Z_t = Y_t = \phi_t = C_t = w_t^o + \frac{1}{\mathrm{M}}$. Thus, if the firms could set their prices with the knowledge of ξ_t^G, inflation would be at steady state Π. Hence, the exogenous shock ξ_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 creates bubbles into the risky asset market, since the uninformed investors do not observe the technology shock. This is the main driver in the permanent break of the dividend process.

4 | CENTRAL BANK POLICY

The central bank targets on constant inflation rate Π, and aims to maximize the welfare of all households in every period by setting the nominal return r_t^{fn} on the risk-free assets in the previous period.

Recall that the technology shock follows $\ln G_t = \ln G_{t-1} + \xi_t^G$, where $\xi_t^G \sim WN(0, \sigma_G^2)$, and that the non-stationary aggregate net profits $\lambda_t = Y_t - \delta_t$ are paid out as aggregate dividendD_t. Thus, it is obvious that the conditional expected dividend $E_t(D_{t+1}) = D_t$ is not equal to the realized D_{t+1}. The informed investors have private information about future performance of aggregate firms in advance since they recognize G_t that affects net profits and thus D_{t+1}. However, the central bank does not have this private information and it observes only D_t. Ilomäki and Laurila (2017) show that, with a lag, the fundamental value manages to prevent P_t and V_t from drifting apart for long periods.

In addition, assume that the central bank considers households risk-neutral investors, which makes the equilibrium price and the fundamental value cointegrated, $P_t - V_t \sim I(0)$. This is because the informed investors are risk-averse ($\omega_i > 0$), while the uninformed ones are risk-neutral ($\omega_u = 0$), and the possible wedge thus has a constant component. Hence, the central bank assumes that $V_t = \frac{D_{t+1}}{r_t^{fn} + \omega_i} \Rightarrow \frac{D_t}{r_t^{fn} + \omega_i} = V_t^B$, which represents a proxy for the fundamental value of the aggregate stock. In addition, the uninformed investors utilize their correlated animal spirits, and $P_t = \frac{D_{t+1} + \omega_i \alpha_{t+1}/r_t^{fn}}{r_t^{fn} + \omega_i} = \Omega_t$. The central bank aims to maximize the aggregate utility of all households,

$$Max\left\{ C_t^i + C_t^u - \left(\frac{1}{2}\right)\left(\mathrm{var}\left[C_t^i\right] + \mathrm{var}\left[C_t^u\right]\right) \right\}.$$

The goods market clearing condition $C_t = C_t^i + C_t^u$ implies that $\mathrm{var}(C_t^i)$ is proportional to $\mathrm{var}(C_t^u)$. Then, the central bank aims to minimize the difference $\mathrm{var}(C_t^i)$ - $\mathrm{var}(C_t^u)$. The general equilibrium of Equation (14) means that, in effect, the central bank minimizes the difference between informed (w_t^{oi}) and uninformed (w_t^{ou}) households' investing wealth before consuming, Thus, it aims to minimize the volatility of w_t^o between households in the general equilibrium. 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

$$1 + r_{t+1}^{fn} = \left(1 + r_{t+1}^{r}\right) E_t[\Pi_{t+1}] \left(\frac{\Pi_t}{\Pi}\right)^{\lambda_\Pi} \left(\frac{\Omega_t}{V_t^B}\right)^{\lambda_A}, \tag{15}$$

where $\Pi_t \equiv \frac{p_t}{p_{t-1}}$ denotes gross inflation, Π is the inflation target, and $\left(1 + r_{t+1}^{r}\right)$ is the gross real risk-free rate. Rule (15) assures that the real interest rate reacts to the changes in inflation with strength $\lambda_\Pi > 0$, and $\frac{\Omega_t}{V_t^B} > 1$ refers to a positive irrational bubble in the stock market. Recall Figure 2, which shows the reduction in the relative wedge when the central bank lifts the nominal risk-free rate. Thus, Figure 2 illustrates how the lift in the risk-free rate reduces the volatility of investing wealth before consuming between informed and uninformed households.

To see the rule in action, consider the following numerical example. Suppose that the gross inflation target is $\Pi = +1.02$, the current gross inflation is $\Pi_t = +1.04$, the expected gross inflation is $E_t[\Pi_{t+1}] = +1.04$, $\lambda_\Pi = +0.6$, $\lambda_A = +0.1$, and $\Omega_t = V_t^B$. Then, according to the rule, the central bank sets $r_{t+1}^{fn} = +0.094$ as the nominal risk-free for the next period. This results in $r_{t+1}^{r} = +0.052$, taken that the expected gross inflation is +1.04. Suppose now that there is a significant positive bubble in the stock markets, say, $\frac{\Omega_t}{V_t^B} = 1.3$. Then, the central bank sets the nominal risk-free for the next period as $r_{t+1}^{fn} = +0.124$, resulting in $r_{t+1}^{r} = +0.081$ at the expected gross inflation rate +1.04.

Since the central bank aims to minimize the volatility of investing wealth before consuming between households, the key variable in the general equilibrium is w_t^o. Thus, asymmetric information about the fundamental value of the stock market among households is the key issue concerning the aggregate household welfare. The informed investors are able to calculate the non-bubble stock market price so that they make right investing decisions, but the uninformed ones tend to make mistakes, which results in larger variance in their consumption when they are old compared to the variance of the informed ones. Thus, the goal of the central bank is to minimize the volatility of investing wealth before consuming between informed and uninformed households by following Equation (15) with $\lambda_A > 0$.

Corollary: Equation (15) works with $\lambda_A > 0$, if uninformed investors are risk-neutral.

Proof: Since there are uninformed households with biased gut feeling, it is likely that there is an upward trend in the equilibrium prices so that $\frac{\Omega_t}{V_t^B} > 1$. The central bank rises the nominal risk-free rate r_t^{fn} taking into account that $E_t(D_{t+1}) = D_t$, and $\lambda_A > 0$ in Equation (15). According to Proposition 1 and the basic result (7), the increase in r_t^{fn} does not have an effect in the equilibrium price, if the uninformed households use their gut feeling without discounting anticipated future dividends. However, the informed households shift a portion from their wealth to the risk-free asset thus increasing the uninformed investors' demand for the risky asset. The fundamental value of the stock $V_t = \frac{D_{t+1}}{r_t^{fn} + \omega_i}$ decreases, which increases the wedge between Ω_t and V_t^B. This is in contradiction with the assumption $\lambda_A > 0$ in Equation (15). However, according to Proposition 2, if the uninformed households are risk-neutral and discount their anticipated dividends, $\lambda_A > 0$ holds. ***Q.E.D.***

5 | CONCLUSIONS

The paper presents a general equilibrium model where the central bank aims to maximize the aggregate real incomes of the households knowing that infinite bubbles are impossible. Following Conlon (2015), asymmetric information is incorporated by assuming that the uninformed investors use their gut feeling (i.e., animal spirits) when assessing stock market valuation. This captures the idea of Martin and Ventura (2012) that investors' sentiments are crucial in developing bubbles. Because the uninformed investors make mistakes on pricing, the central bank must act as a social planner in order to prevent social losses caused by the bursting of super bubbles.

The analysis shows reasonable conditions under which the leaning against the wind policy is effective. In the seminal papers of Shiller (1984, 2014), the uninformed (ordinary) investors do not discount their gut feeling anticipation on future dividends, which makes leaning against the wind policy ineffective. The lift of the risk-free rate does not have affect the equilibrium price, which increases the weight of the animal spirits component in the determination of the market price. Then, if the gut feeling of uninformed investors suggests upward trend in the stock market prices, the central bank's action is not only ineffective but make things even worse by boosting the bubble or inflation or both.

In this paper, uninformed investors discount risk-neutrally their anticipated future dividends from the risky investment. A rise in the risk-free rate makes them reduce their target price in the stock market, thus lowering the informed investors' market valuation of the risky asset. Leaning against the wind policy is effective. Moreover, the paper shows that an irrational bubble may have similar effects on stock market prices as a rational bubble, where all investors are aware of it. This happens if undiscounted animal spirits demand prevails among uninformed investors.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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APPENDIX A

Demand per share of risky asset for informed investor is

$$x_t^{ri} = \frac{E_t(r_{t+1}) - r_t^{fn}}{\omega_i}, \tag{A1}$$

where $\omega_i = \nu\sigma_r^2$ is the constant risk premium of the informed investors. Define the net return on the risky share as $r_{t+1} \equiv \frac{P_{t+1}+D_{t+1}}{P_t} - 1$, plug into Equation (A1), assume $E_t\left(r_{t+1}^{fn}\right) = r_t^{fn}$ and recall that the informed investors have private information on D_{t+1}, $E_t(\Delta D_{t+1}) = 0$. Then,

$$x_t^{ri} = \frac{E_t[(P_{t+1} + D_{t+1}/P_t) - 1] - r_t^{fn}}{\omega_i}. \tag{A2}$$

Plug Equation (A2) into the market clearing condition per share, $x_t^{ri} + \frac{x_t^{ru}}{P_t} = 1$, and get

$$\frac{E_t[(P_{t+1} + D_{t+1}/P_t) - 1] - r_t^{fn}}{\omega_i} + \frac{x_t^{ru}}{P_t} = 1. \tag{A3}$$

Solving P_t from Equation (A3) produces

$$P_t = \frac{E_t\left(P_{t+1} + D_{t+1} + \omega_i x_t^{ru}\right)}{\left(1 + r_t^{fn} + \omega_i\right)}. \tag{A4}$$

Assume $E_t\left(r_{t+1}^{fn}\right) = r_t^{fn}$ and recall the constant risk premium ω_i for informed investors. Solve forward for k periods and get

$$P_t = E_t\left[\sum_{s=1}^{k} \frac{D_{t+k} + \omega_i x_{t+k-1}^{ru}}{\left(1 + r_t^{fn} + \omega_i\right)^k}\right] + E_t\left[\frac{P_{t+k}}{\left(1 + r_t^{fn} + \omega_i\right)^k}\right]. \tag{A5}$$

The second term on the right-hand side of Equation (A5) shrinks to zero as the horizon k increases so that $\lim_{k\to\infty} E_t\left[\frac{P_{t+k}}{\left(1 + r_t^{fn} + \omega_i\right)^k}\right] = 0$, and

$$P_t = E_t\left[\sum_{s=1}^{\infty} \frac{D_{t+s} + \omega_i x_{t+s-1}^{ru}}{\left(1 + r_t^{fn} + \omega_i\right)^s}\right]. \tag{A6}$$

Recall that the technology process follows $\ln G_t = \ln G_{t-1} + \xi_t^G$, where $\xi_t^G \sim WN\left(0, \sigma_G^2\right)$. This makes the dividend process non-stationary so that $E_t(\Delta D_{t+1}) = 0$. Recall that the informed investors have private information on D_{t+1}, and that people live only for two periods. However, the equilibrium price should reflect all discounted dividends in the future. Thus, Equation (A6) reduces to perpetuity valuation:

$$P_t = \frac{D_{t+1} + \omega_i x_t^{ru}}{r_t^{fn} + \omega_i}. \tag{A7}$$

APPENDIX B

The animal spirits anticipation α_{t+1} is the uninformed investors' estimation error of D_{t+1}. Then, $x_t^{ru} = \frac{\alpha_{t+1}}{r_t^{fn}}$ so that $\frac{x_t^{ru}}{P_t} = \frac{\alpha_{t+1}}{P_t r_t^{fn}}$ indicates the excess demand per share compared to the demand of the informed investors. Assume that uninformed investors are risk-neutral, and, based on their gut feeling about D_{t+1}, they invest all their wealth to the stock market, if it offers the highest expected returns. Thus, $P_t = \frac{E_t\left(D_{t+1} + P_{t+1} + x_t^{ru}\omega_i\right)}{\left(1 + r_t^{fn} + \omega_i\right)}$ turns in any state of demand x_t^{ru} to

$$P_t = \frac{E_t\left(D_{t+1} + P_{t+1} + \omega_i \alpha_{t+1}/r_t^{fn}\right)}{\left(1 + r_t^{fn} + \omega_i\right)}. \tag{B1}$$

Use the same procedure as in Appendix A and get

$$P_t = \frac{D_{t+1} + \omega_i \alpha_{t+1}/r_t^{fn}}{r_t^{fn} + \omega_i}. \tag{B2}$$