2022

Monetary and Macroprudential Policies, Output, Prices, and Financial Stability

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Monetary and macroprudential policies, output, prices, and financial stability

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A B S T R A C T

We examine the time-varying causal link between monetary policies and macroeconomy, macroprudential policies and financial stability in China. We find that expansionary monetary policy leads to output growth, tightening monetary policy leads to price stability, and tightening quantitative monetary policy or expanding price-based monetary policy is effective in maintaining financial stability. In response to stagnation or deflation, the central bank implements an expansionary monetary policy. To prevent financial turbulence, the central bank pursues an expansionary quantitative monetary policy or a tight price-based monetary policy. In addition, macroprudential policy should be used in conjunction with monetary policy to maintain financial stability.

Keywords:
Monetary policy
Macroprudential policy
Output
Price
Financial stability

1. Introduction

There is no doubt that monetary policy is vital to economic development and growth. But the choice and interplay between quantitative and price-based monetary policies remains a contentious topic. As the velocity of money circulation gradually declines, quantitative monetary policy tools have become less effective. The effective implementation of price-based monetary policy relies on a sound financial system. However, current Chinese financial market is not yet mature and robust. As China is transitioning from quantitative monetary policy to price-based monetary policy, there are many intriguing and important issues for scholars to explore. Are monetary policies effective in regulating macroeconomy? How does macroeconomy respond to shifts in monetary policies? How can we model the causal link between monetary policy and macroeconomic variables if it is "unstable" or time sensitive?

Before the 1970s and 1980s, most of the discussions about macroeconomic operation were based on the Monetarism theoretical framework of monetary quantity theory (Friedman, 1956, 1970). With the shift from monetarism theory to the new Keynesianism sticking price theory, and the combination of New Keynesian theory with the Dynamic Stochastic General Equilibrium (DSGE) model (Calvo, 1983; Adolfson et al., 2008; Caraiani, 2015), the macroeconomic analysis framework which includes real output, inflation, and interest rates has become the mainstream of modern economics research.

Since 1982, Western developed countries, represented by the United States, have shifted their monetary policy focus away from controlling the money supply towards interest-rate targeting (Zhang, 2012). This trend has attracted many scholars to study the effects

of price-based monetary policy. For example, Bekaert et al. (2013) show that lowering the Fed fund rate can reduce the risk premium of the stock market; Benchimol and Fourçans (2017) document that monetary policies have the same directional effect on output and inflation, and are more effective during economic crises. Coibion et al. (2017) argue that contractionary monetary policies increase inequality in total income, total expenditure and consumption, while monetary policy shocks are important factors in causing the cyclical variation in income and consumption inequality. However, when the policy interest rate reaches the lower limit which is close to zero, the conventional monetary policy represented by "prices" is not always effective (Luciani, 2015; Berger & Bouwman, 2017).

In order to solve the liquidity shortage problem faced by financial markets and institutions, central banks in some countries or regions have adopted nonconventional monetary policies to directly provide liquidity to the market and stimulate economic recovery. Rogers et al. (2014) find that the nonconventional monetary policies, such as the Quantitative Easing (QE) policy by the US Federal Reserve and the Bank of Japan, and the Securities Market Plan (SMP) by the European Central Bank, could effectively enhance financial market activities. Bhar et al. (2015) believe that the Fed's QE policy could boost confidence in the stock market significantly, but the impact on long-term interest rates and employment is less pronounced. Meinusch and Tillmann (2016) confirm the effectiveness of the Fed's QE policy. They document that QE policy has a certain degree of impact on real economic activity, inflation, interest rates, and stock prices. Eser and Schwaab (2016) show that asset purchases in the European SMP can improve the liquidity of the sovereign bond markets and reduce the default risk premium. After studying the spillover effects, Xu (2018) confirms that the zero lower bound of monetary policy can enhance the correlation between different financial markets.

The current price-based monetary policy system in China is far from mature, and the interest rate transmission mechanism is still under development (Guo et al., 2016). China has been mostly following quantitative monetary policies, which are the focus of a lot of research. For example, Wang et al. (2012) show that the narrow money supply is the most important and most effective factor in explaining inflation. Liu and Zhang (2016) find that an increase in the money supply growth rate can stimulate output growth through consumption and investment. Han and Liu (2017) confirm that quantitative monetary policy has always been the key player in macroeconomic development process in China.

As the Chinese financial market becomes more open and the interest rate marketization reform gradually advances, more scholars have shifted their research attention to price-based monetary policies, focusing on the feasibility and necessity of using price-based monetary tools to replace the quantitative counterparts. For example, Qian et al. (2015) find that, as the effectiveness of interest rate transmission in China increases, private enterprises are more sensitive to changes in borrowing interest rates. Li et al. (2016) urge the regulators to shift monetary policy from traditional quantitative tools to price-based instruments, such as interest-rate targeting. Hu (2017) points out that transitioning to price-based tools can enhance the effectiveness and independence of monetary policy.

In addition, some scholars believe that a mixed monetary policy is more appropriate for steady economic development in China. Using a DSGE model, Li and Wang (2011) show that the effect of interest rate on macroeconomy is significant but the duration is shorter, while the money supply effect is milder but more persistent. Thus, there is some merit to use a reasonable mix of quantitative and price-based monetary tools. Guo et al. (2015) find that changes in both money supply and interest rates affect China's economic stability, but the former has a greater impact. Based on New Keynes framework analysis, Wu and Lian (2016) demonstrate that mixed monetary policy tools can help smooth out macroeconomic fluctuations and improve the social welfare effect significantly. Chen et al. (2018) suggest that with the openness of the capital account, it is recommended to implement a mixed monetary policy with a focus on price-based tools.

Previous studies either examine the macroeconomic effect of monetary policy, or evaluate the optimal money supply and interest rates based on monetary policy rules. Few scholars focus on both the effects of using monetary policy to regulate macroeconomy and the corresponding response characteristics using a bidirectional analysis. Additionally, scholars usually set output growth and inflation as the ultimate goal of monetary policy. Most of their macroeconomic analysis frameworks include only monetary policy, output, and inflation. However, as a well-functioning and stable financial system plays a critical role in the development of a country's real economy, it is sensible to include a financial market variable in the analysis. Does financial stability need to be included in the ultimate goal of monetary policy and be evaluated? Can monetary policies shoulder the responsibility of maintaining financial stability? These are all frontier issues in the field of monetary policy (Borio, 2014).

In addition, since the global financial crisis in 2008, many countries around the world have gradually adopted macroprudential policy, in conjunction with macroeconomic policies, to prevent financial risks. The use of two pillars of macroprudential and macroeconomic policies is the key to the stable growth and risk control of modern economy. Thus, what role does macroprudential policy play in regulate financial stability? What is the relationship between macroeconomic and macroprudential policies? How to optimally use different macroprudential policies? The answers to these questions have far-reseaching practical and guiding significance for decision makers.

Furthermore, given that central banks frequently adjust their monetary policies and macroprudential policies according to changes in economic conditions, it is important to use the time-varying estimation framework to study the causal relation between monetary policies and macroeconomy (Horvath et al., 2014), macroprudential policies and financial stability. Swanson (1998) developed a rolling window method to test the Granger causality between money and output. However, setting the length of the time window is subjective and arbitrary. If the chosen length is not reasonable or appropriate, the robustness and accuracy of the empirical results will be questionable. Pre-setting the financial crisis of 2008 as a transition point, Li and Liu (2014) analyze the reconstruction of the macroeconomic policy framework before and after 2008, avoiding the subjectivity of the rolling window method. But this one-time structural change is too simplistic to capture the real time-varying dynamics between monetary policies and macroeconomy, macroprudential policies and financial stability.

Building on the nonlinear Markov Switching Causality (MSC) model proposed by Psaradakis et al. (2005), we define two state variables that directly measure "on" or "off" states of the causal relationship between monetary policies and macroeconomy,

macroprudential policies and financial stability in China, and construct a nonlinear Markov Switching Causality - Vector Error Correction (MSC-VEC) model. This model allows us to characterize the time-varying dynamic causal link based on the state (or regime) change endogenous to the sample data, making it possible to identify when changes in causality might have occurred and connect such changes with the actual monetary and macroeconomic events.

This paper contributes to the literature in the following ways. First, under the same analytical framework, we not only examine the regulating effect of monetary policies on macroeconomy, but also analyze how the central bank responds to macroeconomic shocks. Second, in addition to output growth and price stability, we also consider financial stability as one of the ultimate goals of monetary policy, and assess the causal relationship between monetary policies and financial stability, macroprudential policies and financial stability. This allows us to evaluate the effect of monetary and macroprudential policies more comprehensively, and identify the coordination between policies more clearly. Third, we find that quantitative and price-based monetary policies have a complementary effect on prices and financial stability, but not on output growth. Fourth, we identify the historical periods when quantitative or price-based monetary tools are effective in regulating macroeconomy, and when monetary policies are responsive to changes in macroeconomy based on the transition probabilities of endogenous state variables, providing some insights for policymakers regarding monetary instrument selection and implementation.

The reminder of the paper is organized as follows. Section 2 outlines our theoretical framework. Section 3 discusses the construction of the nonlinear MSC-VEC model. Section 4 presents the empirical results of the time-varying dynamic causality relationship between monetary policies and macroeconomy. Section 5 examines the causal relationship between three types of macroprudential policy tools and financial stability. We summarize and conclude in Section 6.

2. Theoretical framework

2.1. Macroeconomic operation model

In the basic aggregate demand equation (IS curve), current output is a function of the previous output, expected output, and real interest rate. However, one lesson we have learned from the 2008 financial crisis is that the impact of financial factors on macroeconomy can be significant. Asset prices can affect the macroeconomic operation through the wealth effect, the financial accelerator effect and the Tobin's Q effect. Previous research has revealed that financial stability plays a pivotal role in a well-running economy. Empirical studies by Iacoviello (2015), Ma and Wang (2018), and Furlanetto et al. (2019) confirm the impact of financial shocks on output, providing some theoretical foundation for this paper to introduce financial stability in the aggregate demand equation. Furthermore, in developed countries, because the monetary policy transmission mechanism is relatively mature and the correlation between money supply and interest rate is relatively high, usually either money supply or interest rate is included in the aggregate demand equation. However, China's monetary policy system is not yet robust. How money supply and interest rate correlate is not clear to us. At the same time, in the household utility function, money and consumption are not independent (McCallum, 2001). Therefore, it is necessary to incorporate both money supply and interest rate into the aggregate demand equation. The expanded aggregate demand equation, which includes money supply and financial stability, can be expressed as:

$$y_t = \theta_y E_t y_{t+1} + (1-\theta_y) y_{t-1} + \theta_r (R_t - E_t \pi_{t+1}) + \theta_m \Delta M_t + \theta_{fs} FS_t + \varepsilon_{y,t} \tag{1}$$

where y_t, π_t, R_t, ΔM_t, and FS_t are the output gap, inflation, nominal interest rate, nominal money supply growth rate, and financial stability measure at time t, respectively. E_t represents the expected value of a variable at time t, and $\varepsilon_{y,t}$ represents the aggregate demand shock, $\varepsilon_{y,t} \sim N(0, \sigma_y^2)$.

To describe the dynamic evolution mechanism of inflation in China's economy, we follow Scheibe and Vines (2005, p. 4957) and Ma et al. (2017) to include both forward- and backward-looking factors in the aggregate supply equation. Note that although financial stability is not included in the aggregate supply equation, it can affect aggregate demand, and in turn affect inflation. The aggregate supply equation that considers both forward- and backward-looking factors can be expressed as:

$$\pi_t = \nu_\pi E_t \pi_{t+1} + (1-\nu_\pi)\pi_{t-1} + \nu_y y_t + \varepsilon_{\pi,t} \tag{2}$$

As mentioned above, financial shocks can have a significant impact on macroeconomic operations. To accommodate this, we include a financial stability equation in the macroeconomic operation model. Following Tan and Wang (2015), and Ma et al. (2017), we construct the following financial stability equation:

$$FS_t = \delta_{fs} FS_{t-1} + \delta_y y_t + \delta_r R_t - \lambda y_t + \varepsilon_{fs,t} \tag{3}$$

where, λy_t represents the countercyclical regulation of macroprudential policies on financial cycle, λ is the degree of control.

2.2. Expanded monetary policy rules

Monetary policy rules refer to the ones followed by central banks when adjusting the monetary policy instruments such as the money supply and/or interest rates based on changes in macroeconomic conditions. Depending on monetary tools used, traditional monetary policy rules can be classified as quantitative McCallum rules or price-based Taylor rules (McCallum, 1988; Taylor, 1979). The traditional McCallum rule equation can be expressed as follows:

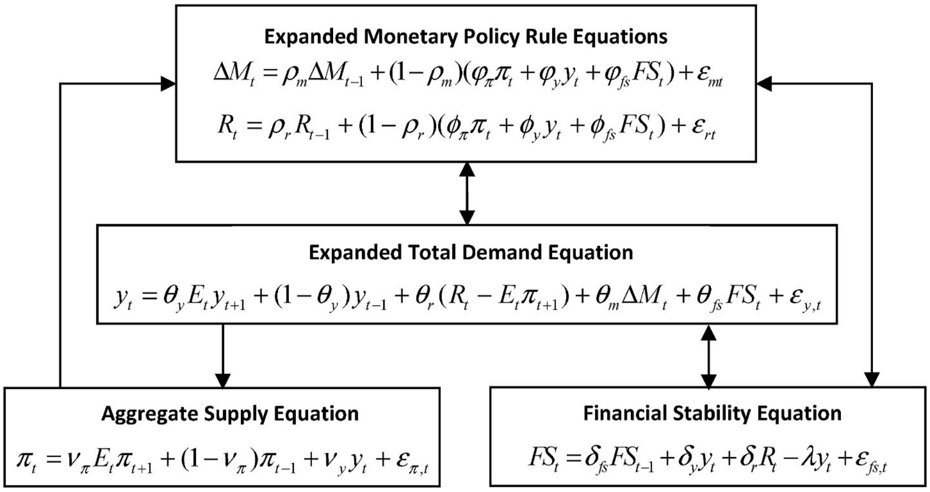

Fig. 1. Theoretical Framework to Analyze the Relationship between Two-pillar policies, macroeconomy, and financial stability.

$$\Delta m_t = \Delta y^* - \Delta v_t + 0.5(\Delta y^* - \Delta y_{t-1}) \tag{4}$$

where Δm_t is the base money supply growth rate, Δy^* is the target nominal GDP growth rate, and Δv_t is the money circulation rate.

Note that McCallum rule does not consider inflation - an important economic indicator. Taylor rule not only can determine the value of the interest rate by minimizing the loss function, but also makes it clear that the nominal interest rate is a function of output and inflation. In addition, Taylor (2000) pointed out that for developing countries, the interest rate in the Taylor rule should be replaced by the base currency. Following Esanov et al. (2005), and Sargent and Surico (2011), we use M1 as the total money supply, and assume the quantitative monetary policy equation follows Taylor rule. Since money supply is an intermediate rather than the ultimate goal of monetary policy, the central bank needs to consider the money supply in the previous period when using quantitative monetary tools. For this reason, we include the lagged money supply in quantitative monetary policy rule equation:

$$\Delta M_t = \rho_m \Delta M_{t-1} + (1-\rho_m)(\varphi_\pi \pi_t + \varphi_y y_t) + \varepsilon_{mt} \tag{5}$$

where ΔM_t is the nominal money supply growth rate, ρ_m is the money supply smoothing parameters, ε_{mt} is the money supply shock.

The price-based monetary policy rule equation takes the following form:

$$R_t = \rho_r R_{t-1} + (1-\rho_r)(\varphi_\pi \pi_t + \varphi_y y_t) + \varepsilon_{rt} \tag{6}$$

where ρ_r is the interest rate smoothing parameter, and ε_{rt} represents interest rate shocks.

To account for the impact of financial risk on macroeconomy, we follow Jiang et al. (2018) and include a financial stability (FS) measure in the monetary policy rule model. With a FS variable, the monetary policy rule equations become:

$$\Delta M_t = \rho_m \Delta M_{t-1} + (1-\rho_m)(\varphi_\pi \pi_t + \varphi_y y_t + \varphi_{fs} FS_t) + \varepsilon_{mt} \tag{7}$$

$$R_t = \rho_r R_{t-1} + (1-\rho_r)(\varphi_\pi \pi_t + \varphi_y y_t + \varphi_{fs} FS_t) + \varepsilon_{rt} \tag{8}$$

2.3. Theoretical analysis framework for the relationship between monetary policies and macroeconomy

Based on the traditional Keynesian three-equation model (IS curve, Phillips curve, and monetary policy rule), we expand the monetary policy rule equations and aggregate demand equation by introducing a financial stability variable, and construct the aggregate supply equation with forward- and backward-looking factors. Fig. 1 illustrates our theoretical analysis framework.

The central bank should implement monetary policies and macroprudential policies selectively based on output, financial conditions, and price information in the market. Subsequently, monetary policies affect money supply and interest rates, and in turn influence output growth, price stability, and financial stability. Furthermore, macroprudential policy tools can be used to reduce financial risks and increase the resilience of the financial system. The expanded monetary policy rule equations, the expanded aggregate demand equation, the aggregate supply equation, and the financial stability equation together constitute the two-pillar regulation system discussed in this paper.

3. Construction of the nonlinear MSC-VEC model

There is a consensus in the academic community that Granger (1969, 1980) causality test is one of the most effective and reliable

methods to test a potential causal relationship between two variables. For stationary time series data, the Granger causality test can be performed using the vector autoregressive (VAR) model. For non-stationary time series data, one can make them stationary by differencing the data first, and then use the VAR model to carry out Granger causality test. Another method is to introduce an error correction term and use the Vector Error Correction (VEC) model to perform Granger causality analysis. Since the VEC model can discern the long-term equilibrium and short-term dynamic relationship between two variables, in order to better fit the long-term and short-term relationships between policies and macroeconomy, this paper first constructs a linear p-order VEC model with a bivariate time series, namely:

$$\begin{pmatrix} \Delta Y_{1,t} \\ \Delta Y_{2,t} \end{pmatrix} = \begin{pmatrix} \mu_1 \\ \mu_2 \end{pmatrix} + \sum_{k=1}^{p} \begin{pmatrix} \alpha_1^{(k)} & \beta_1^{(k)} \\ \beta_2^{(k)} & \alpha_2^{(k)} \end{pmatrix} \begin{pmatrix} \Delta Y_{1,t-k} \\ \Delta Y_{2,t-k} \end{pmatrix} + \begin{pmatrix} \varphi_1 \\ \varphi_2 \end{pmatrix} ecm_{t-1} + \begin{pmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{pmatrix}$$

$$\begin{pmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{pmatrix} \sim i.i.d.N\left(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma_1^2 & \rho\sigma_1\sigma_2 \\ \rho\sigma_1\sigma_2 & \sigma_2^2 \end{pmatrix} \right) \tag{9}$$

for $t = 1, \ldots, T$. $\Delta Y_{1,t}$ and $\Delta Y_{2,t}$ are the first difference of policy variables and macroeconomic variables, respectively. The error correction term ecm_{t-1} represents short-term deviation from long-term equilibrium. φ_1 and φ_2 are the coefficients of the error correction term, which measure the adjustment magnitude of the deviations from long-term equilibrium. Model (9) describes the regulating effect of policies on macroeconomy, as well as the response behavior of policy instruments to changes in macroeconomy.

If at least one of $\beta_1^{(k)}, k = 1, \ldots, p$ is nonzero, we say $\Delta Y_{2,t}$ Granger causes $\Delta Y_{1,t}$; on the other hand, if at least one of $\beta_2^{(k)}, k = 1, \ldots, p$ is nonzero, then $\Delta Y_{1,t}$ Granger causes $\Delta Y_{2,t}$. Note that the model represented by (9) can only describe the "static" linear Granger causality between $\Delta Y_{1,t}$ and $\Delta Y_{2,t}$. A growing body of literature has shown that the causal link between policy variables and macroeconomic variables appears to be "unstable" and time sensitive. In order to capture this potential time-varying feature, we follow Psaradakis et al. (2005) to introduce two state variables, and construct the nonlinear Markov Switching Causality - Vector Error Correction (MSC-VEC) model. This model can characterize the time-varying characteristics of parameters based on the states endogenous to the sample data. The states are defined directly in terms of the causal relationship between two variables. This not only allows us to describe the time-varying causal dynamics between policies and macroeconomy, but also makes it possible for us to identify when changes in causality might have occurred and connect such changes with the actual monetary and macroeconomic events.

Specifically, the nonlinear bivariate *p*-order vector error correction model, which includes "Markov regime-switching" state variables can be written as:

$$\begin{pmatrix} \Delta Y_{1,t} \\ \Delta Y_{2,t} \end{pmatrix} = \begin{pmatrix} \mu_{10} + \mu_{11} S_{1,t} \\ \mu_{20} + \mu_{21} S_{2,t} \end{pmatrix} + \sum_{k=1}^{p} \begin{pmatrix} \alpha_{10}^{(k)} + \alpha_{11}^{(k)} S_{1,t} & \beta_1^{(k)} S_{1,t} \\ \beta_2^{(k)} S_{2,t} & \alpha_{20}^{(k)} + \alpha_{21}^{(k)} S_{2,t} \end{pmatrix} \begin{pmatrix} \Delta Y_{1,t-k} \\ \Delta Y_{2,t-k} \end{pmatrix} + \begin{pmatrix} \varphi_1 S_{1,t} \\ \varphi_2 S_{2,t} \end{pmatrix} ecm_{t-1} + \begin{pmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{pmatrix}$$

$$\begin{pmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{pmatrix} \sim i.i.d.N\left(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma_{1,S_{1,t}}^2 & \rho\sigma_{1,S_{1,t}}\sigma_{2,S_{2,t}} \\ \rho\sigma_{1,S_{1,t}}\sigma_{2,S_{2,t}} & \sigma_{2,S_{2,t}}^2 \end{pmatrix} \right) \tag{10}$$

where $S_{1,t}$ and $S_{2,t}$ are independent discrete state variables, defined in terms of causality "on" (1) or "off" (0) between two variables. We use this model to analyze the short-run dynamics and the long-run equilibrium between policy variables and macroeconomic variables. Depending on the values of $S_{1,t}$ and $S_{2,t}$, we further define another state-indicator variable S_t with four possible states:

$$S_t = \begin{cases} 1 & when\ S_{1,t} = 1\ and\ S_{2,t} = 1 \\ 2 & when\ S_{1,t} = 0\ and\ S_{2,t} = 1 \\ 3 & when\ S_{1,t} = 1\ and\ S_{2,t} = 0 \\ 4 & when\ S_{1,t} = 0\ and\ S_{2,t} = 0 \end{cases} \tag{11}$$

Assume both state variables $S_{1,t}$ and $S_{2,t}$ follow the first-order Markov chain process. The state transition probability matrix for $S_{1,t}$ can be expressed as follows:

$$P = \begin{pmatrix} p_{11} & p_{01} \\ p_{10} & p_{00} \end{pmatrix} \tag{12}$$

where $p_{ij} = \Pr(S_{1,t} = j | S_{1,t-1} = i),\ i,j = 0,1,$ is the transition probability from state *i* at time *t-1* to state *j* at time *t*. Since the causality states ("on" or "off") are binary, it follows that $p_{00} + p_{01} = 1$, and $p_{10} + p_{11} = 1$. We can rewrite the transition probability matrix (12) as:

$$P = \begin{pmatrix} p_{11} & 1 - p_{00} \\ 1 - p_{11} & p_{00} \end{pmatrix} \tag{13}$$

Similarly, the corresponding state transition probability matrix for $S_{2,t}$ can be expressed as follows:

$$Q = \begin{pmatrix} q_{11} & q_{01} \\ q_{10} & q_{00} \end{pmatrix} \tag{14}$$

$$Q = \begin{pmatrix} q_{11} & 1 - q_{00} \\ 1 - q_{11} & q_{00} \end{pmatrix} \tag{15}$$

The corresponding state transition probability matrix for the state-indictor variable S_t defined in (11) is then

$$\overline{P} = \begin{pmatrix} p_{11}q_{11} & (1-p_{00})q_{11} & p_{11}(1-q_{00}) & (1-p_{00})(1-q_{00}) \\ (1-p_{11})q_{11} & p_{00}q_{11} & (1-p_{11})(1-q_{00}) & p_{00}(1-q_{00}) \\ p_{11}(1-q_{11}) & (1-p_{00})(1-q_{11}) & p_{11}q_{00} & (1-p_{00})q_{00} \\ (1-p_{11})(1-q_{11}) & p_{00}(1-q_{11}) & (1-p_{11})q_{00} & p_{00}q_{00} \end{pmatrix} \tag{16}$$

We use the Expectation Maximization (EM) algorithm (Dempster et al., 1977) and the Maximum Likelihood (ML) technique (Hamilton, 1990; Kim & Nelson, 1999) to estimate the parameters in the nonlinear MSC-VEC model, as well as the filtered probability $\Pr(S_t|I_t)$ and smoothed probability $\Pr(S_t|I_T)$, where I_t represents the information set obtained at time t, and I_T represents all the information sets obtained over the entire sample period, T. Using the filtered probability $\Pr(S_t|I_t)$ and the smoothed probability $\Pr(S_t|I_T)$, we further estimate $\Pr(S_{1,t} = 1|I_t)$, $\Pr(S_{2,t} = 1|I_t)$, $\Pr(S_{1,t} = 1|I_T)$, and $\Pr(S_{2,t} = 1|I_T)$, the probabilities of having a causal relationship between policies and macroeconomic variables at each sample point. We follow Hamilton (1989) to set the probability threshold to 0.5. If $\Pr(S_{1,t} = 1|I_t) > 0.5$ or $\Pr(S_{1,t} = 1|I_T) > 0.5$, we conclude that macroeconomy has a causal effect on policies; on the other hand, if $\Pr(S_{2,t} = 1|I_t) > 0.5$ or $\Pr(S_{2,t} = 1|I_T) > 0.5$, policies have a causal effect on macroeconomy.

4. Nonlinear time-varying dynamic causality measure between monetary policy and macroeconomy

This section presents the empirical results of our MSC-VEC model. We consider both quantitative monetary policy and price-based monetary policy. Macroeconomy is represented by output, inflation, and financial stability. The effects of monetary policies on macroeconomy thus include output effect, price effect, and financial stability effect.

4.1. Data

Following Liu and Sui (2010), Jia et al. (2014), Zhang and Wang (2016), Ma and Wang (2018), we use money supply (M1) as the proxy variable for quantitative monetary policy, and market interest rate (R) as the proxy variable for price-based monetary policy. The market interest rate (R) is measured by the 7-day interbank offered rate. We calculate the quarterly weighted average interbank offered rate based on monthly data as follows.

$$R = \sum_{i=1}^{3} r_i \times \left(v_i \middle/ \sum_{i=1}^{3} v_i \right) \tag{17}$$

where r_i and v_i are the monthly interbank offered rate and the monthly borrowing transaction volume in month i, respectively, during that quarter.

The proxy variables for output and price are gross domestic product (GDP) and inflation rate (INF), respectively. Financial stability is measured using the forecast variance or volatility of Shanghai Composite Index (SCI). The sample period is from the first quarter of 1992 to the first quarter of 2018. The data are from the Wind database and the People's Bank of China Statistical Quarterly.

We first normalize the consumer price index (CPI) time series data using 1992 as the base year, and then use the normalized CPI data to calculate the real GDP. To eliminate the influence of seasonal factors and heteroscedasticity, we apply the X-12 seasonal adjustment to the money supply and real GDP, then take the logarithm of both series. Since the stock market is an integral part of a country's financial system, it is natural to use stock market volatility to measure financial stability. Following He et al. (2016), we use the generalized autoregressive conditional heteroskedasticity (GARCH) model to calculate the volatility of Chinese stock market based on Shanghai Composite Index (SCI).

$$SCI_t = a_0 + a_1 SCI_{t-1} + a_2 SCI_{t-2} + \ldots + \varepsilon_t \tag{18}$$

$$\sigma_t^2 = b_0 + \sum_{m=1}^{p} b_{1,m}\sigma_{t-m}^2 + \sum_{n=1}^{q} b_{2,n}\varepsilon_{t-n}^2 \tag{19}$$

Equation (18) represents the mean equation and Equation (19) is the conditional heteroskedasticity equation. Where SCI_t is the Shanghai Composite Index, ε_t is the perturbation term for the mean equation, σ_t^2 is the forecast variance based on the mean equation, p and q represent the number of lag periods. The optimal lag periods are chosen based on the Akaike and Schwarz information criteria. It is found that the minimum AIC value and SIC value can be obtained when $p = q = 1$. Thus, we estimate a GARCH (1,1) model, and use the resulting forecast variance of Shanghai Composite Index (SCI) as the proxy for financial stability.

To avoid "spurious regression" problems, we test the stationarity of monetary supply (M1), market interest rate (R), gross domestic product (GDP), price (INF) and financial stability (FS) series using unit root test methods such as ADF, PP and KPSS. Table 1 shows that

Table 1
Unit root test.

Variable	ADF Test	PP Test	KPSS Test	Conclusion
M1	−2.8600	−3.3036*	0.2295***	Non-stationary
R	−1.3975	−1.5295	0.2231***	Non-stationary
GDP	−1.6202	−0.9204	1.1574***	Non-stationary
INF	−2.6128	−2.3411	0.1476**	Non-stationary
FS	−5.1109***	−4.6013***	0.0859	Stationary
ΔM1	−7.4925***	−7.5090***	0.0947	Stationary
ΔR	−7.0732***	−7.2338***	0.0970	Stationary
ΔGDP	−7.0429***	−7.2643***	0.2254	Stationary
ΔINF	−6.7726***	−5.4173***	0.0543	Stationary

Note: This table shows the unit root testing results for our data series. Δ represents the first-order difference. The null hypothesis of the ADF test and the PP test is that the series is non-stationary, and the alternative hypothesis is that the series is stationary. The null hypothesis of the KPSS test is that the series is stationary, and the alternative hypothesis is that the data is non-stationary. ***, **, and * indicate the rejection of the null hypothesis at the 1%, 5% and 10% significance levels, respectively.

Table 2
Boundary cointegration test.

Variables	Lags	F-statistic	Test Threshold		
			P	I (0)	I (1)
(M1,GDP)	1	7.8640***	10%	4.04	4.78
(M1,INF)	2	7.2007**	——	——	——
(M1,FS)	3	11.8081***	5%	4.94	5.73
(R,GDP)	2	6.5534**	——	——	——
(R,INF)	3	9.0158***	1%	6.84	7.84
(R,FS)	4	6.6101**			

Note: This table shows the boundary cointegration test results. Please refer to Table CI (iii) in Pesaran et al. (2001) for the thresholds. ***, **, and * indicate the rejection of the null hypothesis of no integration relationship at 1%, 5% and 10% significance levels, respectively.

the M1, R, GDP, and INF data are all non-stationary at the 5% or 1% level. After taking first difference, these series become stationary at the 1% level. That is, they are integrated to the order of one, or I (1). The financial stability (FS) data is stationary at the 1% level, so it is I(0).

4.2. *Boundary cointegration test*

Cointegration tests mainly include Engle-Granger (EG) two-step procedure, Johansen Test, and Bounds Testing Approach. EG two-step method and Johansen Test are appropriate only for testing variables that are integrated to the same order. Additionally, in the case of small samples, estimators from these two methods are prone to estimation bias. The Bounds Testing Approach is not only suitable for testing variables that are integrated to the same order, but also suitable for mixed I(0) and I(1) series. When the sample size is not large, the Bounds Testing Approach is more robust than other cointegration tests (Zhou & Nie, 2013). Since monetary policy variables and macroeconomic variables studied in this paper are a mixture of I (0) and I (1) data, and there are only 105 data points from the first quarter of 1992 to the first quarter of 2018, the Bounds Testing Approach is more appropriate in our case. Following Pesaran et al. (2001), we construct the following autoregressive distributed lag - error correction model (ARDL-ECM):

$$\Delta Y_{2,t} = \omega + \lambda_1 Y_{1,t-1} + \lambda_2 Y_{2,t-1} + \sum_{i=0}^{p} \gamma_i \Delta Y_{1,t-i} + \sum_{i=1}^{p} \eta_i \Delta Y_{2,t-i} + \varepsilon_t \tag{20}$$

where $Y_{1,t}$ and $Y_{2,t}$ represent the monetary policy and macroeconomic variables, respectively; p is the number of lag periods; ε_t is the disturbance term.

Pesaran et al. (2001) and Narayan (2005) obtained the boundary test threshold of F statistics by simulation. If the F statistics is higher than the upper bound value, the null hypothesis is rejected, suggesting that there is a cointegration relationship between monetary policy and macroeconomy. If the F statistics is between the upper and lower bounds, the cointegration relationship cannot be determined; if the F statistics is lower than the lower bound, we accept the null hypothesis, meaning that no cointegration relationship is found. The optimal lag periods are chosen based on the Akaike and Schwarz information criteria. As shown in Table 2, to explore the cointegration relationship between money supply (M1) and output (GDP), price (INF), and financial stability (FS), the minimum AIC and SIC values are obtained when $p = 1$, $p = 2$, and $p = 3$, respectively. To explore the cointegration relationship between market interest rate (R) and output (GDP), price (INF), and financial stability (FS), the minimum AIC and SIC values are obtained when $p = 2$, $p = 3$, and $p = 4$, respectively. Table 2 also shows the results of boundary cointegration test. The F statistics of all Wald tests is greater than the upper bound of the 1% or 5% threshold, indicating a rejection of the null hypothesis. That is, there is a cointegration relationship between each pair of the monetary policy variables (M1 and R) and macroeconomic variables (GDP, INF and FS).

Table 3
Causality relationship between money supply and macroeconomic variables.

Parameter	M1—GDP	M1—INF	M1—FS	Parameter	M1—GDP	M1—INF	M1—FS
p_{11}	0.9502*** (0.0291)	0.4867** (0.1936)	0.7873*** (0.0946)	q_{11}	0.9868*** (0.0166)	0.8716*** (0.0729)	0.8154*** (0.0825)
p_{00}	0.8568*** (0.0744)	0.8154*** (0.0973)	0.7285*** (0.1083)	q_{00}	0.9881*** (0.0146)	0.9165*** (0.0469)	0.9365*** (0.0284)
μ_{10}	2.7625*** (0.4606)	0.5311 (0.4626)	4.0044*** (0.5574)	μ_{20}	2.2643*** (0.3376)	0.0784 (0.0673)	−0.0044 (0.0057)
μ_{11}	1.1307 (0.7781)	3.6332*** (0.7532)	−2.2237*** (0.8088)	μ_{21}	−0.9392** (0.4626)	−0.9065 (0.6564)	−0.2726 (0.4387)
φ_1	−0.0849*** (0.0163)	0.0048 (0.0036)	−0.0065** (0.0028)	φ_2	0.0535*** (0.0173)	−0.0047 (0.0039)	0.0007 (0.0018)
$\alpha_{10}^{(1)}$	−0.4460*** (0.1325)	0.2602*** (0.0891)	0.6265*** (0.0927)	$\alpha_{20}^{(1)}$	0.0122 (0.1280)	0.2420** (0.1056)	0.2510*** (0.0614)
$\alpha_{10}^{(2)}$	——	0.5576*** (0.0938)	0.0440 (0.0881)	$\alpha_{20}^{(2)}$	——	0.3111*** (0.0937)	0.0744** (0.0373)
$\alpha_{10}^{(3)}$	——	——	−0.5969*** (0.0751)	$\alpha_{20}^{(3)}$	——	——	−0.0435** (0.0184)
$\alpha_{11}^{(1)}$	0.7555*** (0.1793)	0.3454* (0.1836)	−0.8588*** (0.1447)	$\alpha_{21}^{(1)}$	0.3742** (0.1630)	0.2580 (0.1921)	−0.7563*** (0.2537)
$\alpha_{11}^{(2)}$	——	−1.1872*** (0.1526)	0.0612 (0.1471)	$\alpha_{21}^{(2)}$	——	−0.1640 (0.1836)	0.2118 (0.2808)
$\alpha_{11}^{(3)}$	——	——	1.1090*** (0.1209)	$\alpha_{21}^{(3)}$	——	——	0.5415** (0.2410)
$\beta_1^{(1)}$	−0.1607 (0.1527)	−0.2805* (0.1688)	−0.0999 (0.4521)	$\beta_2^{(1)}$	0.1038** (0.0524)	0.2561*** (0.0935)	0.2741** (0.1171)
$\beta_1^{(2)}$	——	−0.6543*** (0.1825)	4.7765*** (0.5270)	$\beta_2^{(2)}$	——	−0.1453 (0.1011)	−0.2608* (0.1354)
$\beta_1^{(3)}$	——	——	3.5155*** (0.6545)	$\beta_2^{(3)}$	——	——	0.0198 (0.0995)
σ_{11}	1.4778*** (0.1335)	0.7669*** (0.1719)	1.2872*** (0.1375)	σ_{21}	0.7398*** (0.0749)	1.5736*** (0.1956)	0.6615*** (0.0965)
σ_{10}	1.7354*** (0.2605)	1.7272*** (0.1498)	0.9402*** (0.1363)	σ_{20}	0.9931*** (0.0963)	0.4859*** (0.0553)	0.0460*** (0.0043)

Note: This table reports the parameter estimates for the nonlinear time-varying dynamic causality relationship between money supply (M1) and output (GDP), prices (INF) and financial stability (FS). ***, **, and * indicate statistical significance at the 1%, 5%, and 10%, respectively. The values in parentheses are the standard deviations of the corresponding parameter estimates.

4.3. *Empirical results from the nonlinear MSC-VEC model*

Table 2 shows that there is a cointegration relationship between each pair of monetary policy variables and macroeconomic variables. As mentioned earlier, traditional linear vector error correction models can only identify the “static” linear relationship between two variables. But due to frequent changes in external environment and shocks to the economy, we have good reasons to believe that the causal relationship between monetary policy and macroeconomic variables change over time. Thus, we use the proposed nonlinear MSC-VEC model to identify the time-varying dynamic causal link between monetary policy and macroeconomy.

Tables 3 and 4 present the parameter estimates of our MSC-VEC model. p_{11} and p_{00} are the probabilities of macroeconomy maintaining the same response or no response to monetary policy, respectively; q_{11} and q_{00} are the probabilities of monetary policy maintaining the same regulating effect or no effect on macroeconomy, respectively; μ_{10}, μ_{11}, μ_{20} and μ_{21} are the constant estimates of the monetary policy - macroeconomy system; φ_1 is the coefficient of the error correction term of the monetary policy variable; φ_2 is the coefficient of the error correction term of the macroeconomic variable; α_{10} and α_{11} are the autoregressive coefficients of the monetary policy variable; α_{20} and α_{21} are the autoregressive coefficients of the macroeconomic variable; β_1 and β_2 are the causal coefficients between monetary policy and the macroeconomic variables.

The parameter estimates for the nonlinear time-varying dynamic causality relationship between the money supply (M1) and the macroeconomic variables are shown in Table 3. The estimates of p_{11}, p_{00}, q_{11} and q_{00} are all significant at the 1% level. q_{11} and q_{00} are both greater than 0.80, indicating that the causal effect of money supply on macroeconomy has a strong "inertia" feature. That is, the influence or non-influence of money supply on macroeconomy is very persistent. The error correction coefficients of money supply and macroeconomic variables have opposite signs, confirming their cointegration relationship. At the same time, the cointegration relationship between money supply and output has a significant negative correction effect on money supply, and the cointegration relationship between money supply and financial stability also has a significant negative correction effect on money supply. The error correction coefficient of money supply and price is not significant, indicating that money supply and prices are adjusting too fast to each other (Gujarati, 2011).

In the case of financial stability, the coefficient of one-period lagged money supply to current financial stability is positive and significant at the 5% level, and its absolute value and significance are greater than that of other lag periods. Recall that we use stock market volatility to measure financial stability. A positive coefficient means that an increase in money supply will lead to a higher stock

Table 4
Causality relationship between market interest rate and macroeconomic variables.

Parameter	RATE—GDP	RATE—INF	RATE—FS	Parameter	RATE—GDP	RATE—INF	RATE—FS
p_{11}	0.9157*** (0.0733)	0.5327*** (0.1652)	0.4605*** (0.1493)	q_{11}	0.6393*** (0.1227)	0.9342*** (0.0351)	0.9469*** (0.0263)
p_{00}	0.9151*** (0.0576)	0.8736*** (0.0534)	0.9078*** (0.0365)	q_{00}	0.8857*** (0.0482)	0.8437*** (0.0846)	0.8008*** (0.0861)
μ_{10}	0.0019 (0.0344)	−0.0764 (0.0519)	−0.0138 (0.0447)	μ_{20}	1.2842*** (0.3593)	−0.6425 (0.4810)	0.2189 (0.1746)
μ_{11}	−0.7899** (0.3370)	0.2243*** (0.0558)	0.9895*** (0.0691)	μ_{21}	−0.4045 (0.3660)	0.6501 (0.4872)	−0.2272 (0.1749)
φ_1	−0.0089 (0.0551)	0.0012 (0.0092)	0.2938*** (0.0253)	φ_2	0.0212** (0.0084)	−0.1326*** (0.0353)	−0.0010 (0.0014)
$\alpha_{10}^{(1)}$	0.0922 (0.0618)	0.0149 (0.0910)	0.3062*** (0.0854)	$\alpha_{20}^{(1)}$	0.2265* (0.1212)	0.4011** (0.1902)	−0.6539** (0.2729)
$\alpha_{10}^{(2)}$	0.0496 (0.0561)	0.0780 (0.0890)	0.0775 (0.0858)	$\alpha_{20}^{(2)}$	0.2017* (0.1218)	0.3640* (0.2200)	0.0663 (0.2790)
$\alpha_{10}^{(3)}$	——	0.0964 (0.0859)	0.0941 (0.0844)	$\alpha_{20}^{(3)}$	——	0.1591 (0.2536)	0.0642 (0.2718)
$\alpha_{10}^{(4)}$	——	——	−0.1110 (0.0801)	$\alpha_{20}^{(4)}$	——	——	−0.2549 (0.4195)
$\alpha_{11}^{(1)}$	0.1136 (0.1834)	0.6617*** (0.1131)	−1.6876*** (0.0950)	$\alpha_{21}^{(1)}$	0.3847*** (0.1233)	−0.0821 (0.2175)	1.0807*** (0.2743)
$\alpha_{11}^{(2)}$	0.1064 (0.1838)	0.2625** (0.1184)	−0.4340*** (0.0953)	$\alpha_{21}^{(2)}$	−0.0856 (0.1245)	−0.2233 (0.2438)	−0.1069 (0.2803)
$\alpha_{11}^{(3)}$	——	−0.9009*** (0.1211)	−0.5158*** (0.1045)	$\alpha_{21}^{(3)}$	——	−0.3512 (0.2675)	−0.0858 (0.2727)
$\alpha_{11}^{(4)}$	——	——	1.8008*** (0.0940)	$\alpha_{21}^{(4)}$	——	——	0.2332 (0.4203)
$\beta_1^{(1)}$	0.1699* (0.0942)	−0.0007 (0.0339)	−0.4171*** (0.0312)	$\beta_2^{(1)}$	−0.3541*** (0.0684)	0.0644 (0.1284)	0.0023 (0.0108)
$\beta_1^{(2)}$	0.1285 (0.0946)	0.3000*** (0.0388)	0.1927*** (0.0258)	$\beta_2^{(2)}$	−0.4245*** (0.0604)	0.1826 (0.1254)	−0.0205* (0.0120)
$\beta_1^{(3)}$	——	0.2629*** (0.0355)	−0.0402 (0.0705)	$\beta_2^{(3)}$	——	−0.2589** (0.1233)	−0.0029 (0.0118)
$\beta_1^{(4)}$	——	——	0.8182*** (0.0733)	$\beta_2^{(4)}$	——	——	0.0275** (0.0110)
σ_{11}	0.6650*** (0.0813)	0.0759*** (0.0138)	0.0361*** (0.0081)	σ_{21}	0.0843*** (0.0152)	0.5348*** (0.0488)	0.0460*** (0.0043)
σ_{10}	0.1665*** (0.0292)	0.4386*** (0.0360)	0.4026*** (0.0320)	σ_{20}	1.0864*** (0.0883)	1.9812*** (0.2842)	0.6452*** (0.0966)

Note: This table reports the parameter estimates for the nonlinear time-varying dynamic causality relationship between market interest rate (RATE) and output (GDP), prices (INF) and financial stability (FS). ***, **, and * indicate statistical significance at the 1%, 5%, and 10%, respectively. The values in parentheses are the standard deviations of the corresponding parameter estimates.

market volatility, and thus a lower financial stability. This is because the price effect of money supply suggests that increasing the money supply will lead to inflation. From the perspective of the lenders, inflation makes it difficult for them to identify the good or bad borrowers and/or loan projects. Due to this information asymmetry problem, the lender will assume a higher risk. On the other hand, the borrowers could mistakenly regard the overall price increase as a price increase of their own products only, and expand production by raising more capital from financial institutions. However, a rise in the overall price level makes it impossible for borrowers to achieve the expected rate of return, which in turn increases the default risk that financial institutions face. This is detrimental to financial institutions and even the entire financial system. In addition, two- and three-period lagged financial stability measures have significantly positive causal effects on the current money supply. That is, when financial market volatility increases, the central bank would still subsequently increase the money supply. An increase in money supply is to the disadvantage of financial stability, but it can promote output growth. A turbulent financial market is often accompanied by an economic downturn. In order to stimulate the economy, the central bank may choose to increase the money supply. This indicates that the main objective of the quantitative monetary policy is to promote output growth, rather than maintaining financial stability.

Table 4 presents the results of the causal relationship between market interest rate and three macroeconomic variables. The estimates of the maintaining probabilities p_{11}, p_{00}, q_{11} and q_{00} are all significant at the 1% level. q_{11} and q_{00} are both greater than 0.60, indicating that the causal effect of market rate on macroeconomy has a similar but weaker "inertia" feature as that of the money supply. The error correction coefficients of market rate and macroeconomic variables have opposite signs, confirming their cointegration relationship. At the same time, the cointegration relationship between market interest rate and output has a significant positive correction effect on output, and the cointegration relationship between market rate and price has a significant negative correction effect on price, and the cointegration relationship between market rate and financial stability has a significant positive correction effect on market interest rate.

With regard to the output effect and price effect of market interest rates, as shown in Columns 2, 3, 6 and 7 of Table 4, the β coefficients of one- and two-period lagged market rate on the current output, and the coefficient of three-period lagged market rate on current price are all significantly negative, implying that lowering market interest rate can promote output growth, and raising market

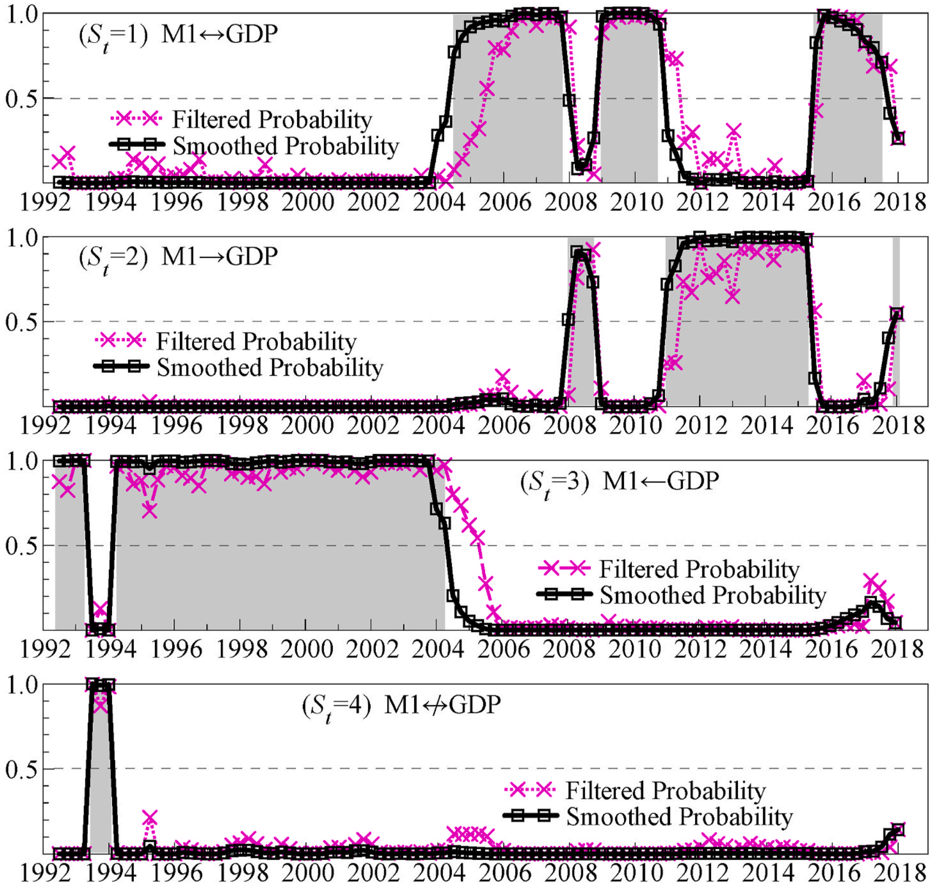

Fig. 2. Probability trajectories of time-varying causal effect between money supply (M1) and output (GDP).

rate can help maintain price stability. This is consistent with the theoretical expectations of the traditional Keynesian theory, confirming the effectiveness of price-based monetary policy on output growth and price stability, as well as the delay in the effect of price-based monetary policy on output and price. Conversely, the β coefficient of one-period lagged output on the current market interest rate, and the coefficients of two- and three-period lagged price on market rate are all significantly positive, indicating that an increase in output or price level will lead to a higher market interest rate. This is in line with the traditional Keynesian view and Taylor rules.

Columns 4 and 8 of Table 4 report the estimation results of the interest rate - financial stability system. The coefficient of four-period lagged market rate on current financial stability is significantly positive and greater than that of other lags, indicating that higher market interest rates may lead to higher stock market volatility and thus weaker financial stability. The price effect of market interest rates suggests that raising market interest rates can keep prices low or stable. Long-term low prices will lead to lower value of investments. Financial institutions' credit assets will depreciate rapidly, which can cause liquidity problems in the financial system, followed by a contraction in credit and ultimately financial fluctuations. To avoid the "financial accelerator" effect of this risk to the real economy, the central bank can implement an expansionary price monetary policy to inject liquidity to the market. In addition, the casual effect coefficient of four-period lagged financial stability on current market interest rate is significantly positive, and its absolute value is greater than those of other lag periods. This means that the central bank may still choose to raise interest rate when facing financial uncertainty. Although an increase in market interest rates may not be beneficial to financial stability, it can help maintain price stability. An unstable financial market is often accompanied by inflation. In order to control inflation, the central bank may still choose to raise interest rates. In another word, the main objective of the price-based monetary policy is to maintain price stability, rather than safeguarding financial stability.

The causality between monetary policy and macroeconomy may be affected by the macroeconomic cycle. To account for this, we calculate the filtered probability $\Pr(S_t|I_t)$ and smoothed probability $\Pr(S_t|I_T)$ of the causal relationship over the entire sample period. The pairwise filtered probability and smoothed probability trajectories between monetary policy variables and macroeconomic variables are depicted in Figs. 2–7. In the figures, $S_t = 1$ represents the state when there is a bi-directional causal effect between monetary policy and macroeconomy; $S_t = 2$ represents the state when only monetary policy has a causal effect on macroeconomy; $S_t = 3$ represents the state when only macroeconomy has a causal effect on monetary policy; $S_t = 4$ represents the state when there is no causal relationship. Note that the filtered probability $\Pr(S_t|I_t)$ is calculated based on the information obtained during t period, while the smoothed probability $\Pr(S_t|I_T)$ is based on the information set of the entire T sample period. Thus, the latter can discern the time-

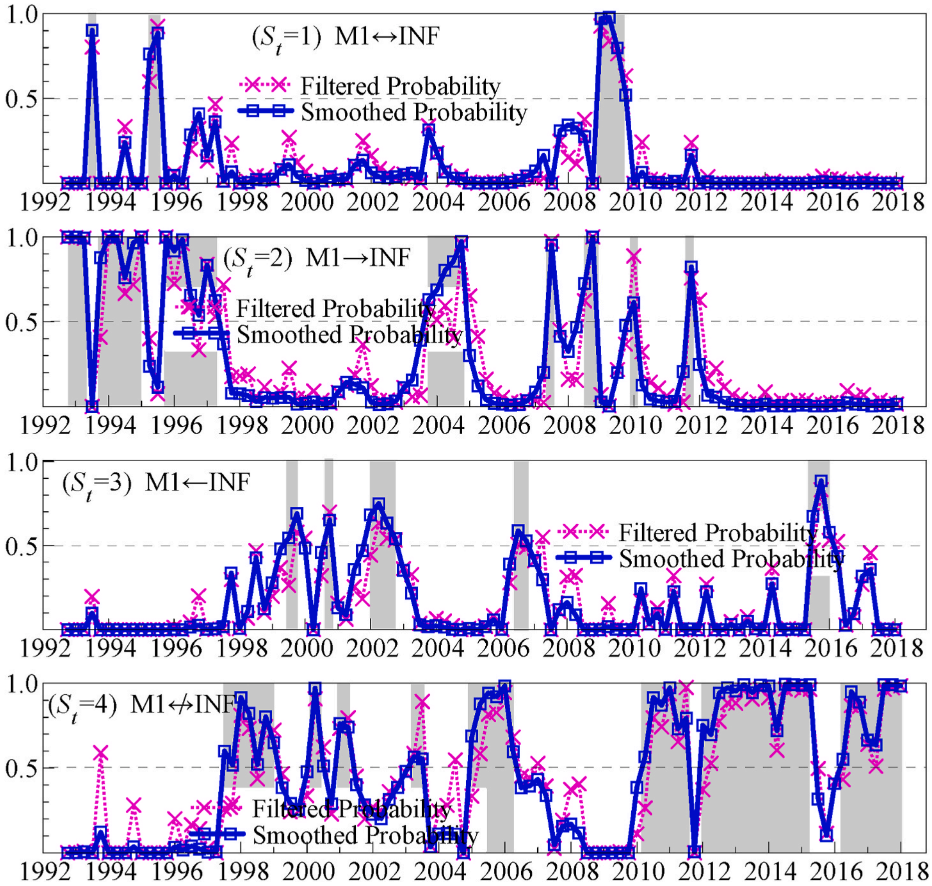

Fig. 3. Probability trajectories of time-varying causal effect between money supply (M1) and prices (INF).

varying dynamic causal relationship more accurately. Based on smoothed probability calculations, the periods when there is a causal effect are shaded.

Fig. 2 depicts the probability trajectories of time-varying causal effect between money supply and output. Over the entire sample period, state $S_t = 4$ only occurs during 1993 and 1994. The other three states occur more often, indicating that the quantitative monetary policy has strong regulatory effect on and responding ability to output. As an intermediate target of monetary policy, money supply can still effectively influence output, and can quickly adjust to output deviations. In this sense, quantitative monetary policy should continue to be implemented.

For price, Fig. 3 shows that states 1, 2, and 3 are short-lived and become even shorter in most recent years, while state 4 dominates, especially during the period of 2012–2018, indicating a much weaker causal relationship between money supply and prices. Quantitative monetary policy not only becomes less efficient in regulating prices, but also is less responsive to price changes. To explain this, note that one of the important premises for quantitative monetary policy to be effective is that "borrowers rely on bank loans" (Guo et al., 2016). With the emergence of shadow banking and the development of Internet finance, social financing channels have increased significantly. Borrowers no longer rely solely on bank loans. At the same time, Internet finance has changed the financial market environment, promoted the innovation of financial products and financial instruments, and thus weakened the effectiveness of monetary policy tools in regulating bank loans and prices (Zhan et al., 2018).

For financial stability, as demonstrated in Fig. 4, the causal relationship between money supply and financial stability is relatively short in the states of 1 and 2. The period of being in state 3 is gradually expanding, while state 4 is gradually shrinking, meaning that the correlation between money supply and financial stability has increased in recent years. Although the quantitative monetary policy is still weak in regulating financial stability, its ability to respond to financial stability has been strengthened. This suggests the need to consider the impact of financial stability when implementing quantitative monetary policy.

Figs. 5–7 plot the probability trajectories of time-varying causal effect between interest rate and three macroeconomic variables. Fig. 5 shows that the causal relationship between market interest rate and output is relatively short in the first two states. State 3 shows up more often in recent years, while state 4 occurs less often, implying that the causal effect between interest rate and output has increased over time. Although the price-based monetary policy has a weak effect on output, it becomes more responsive to output recently. Note that China is transitioning from quantitative monetary policy to price-based monetary policy. The central bank hopes to regulate output through price-based monetary policy. However, because the market-based interest rate system is still under

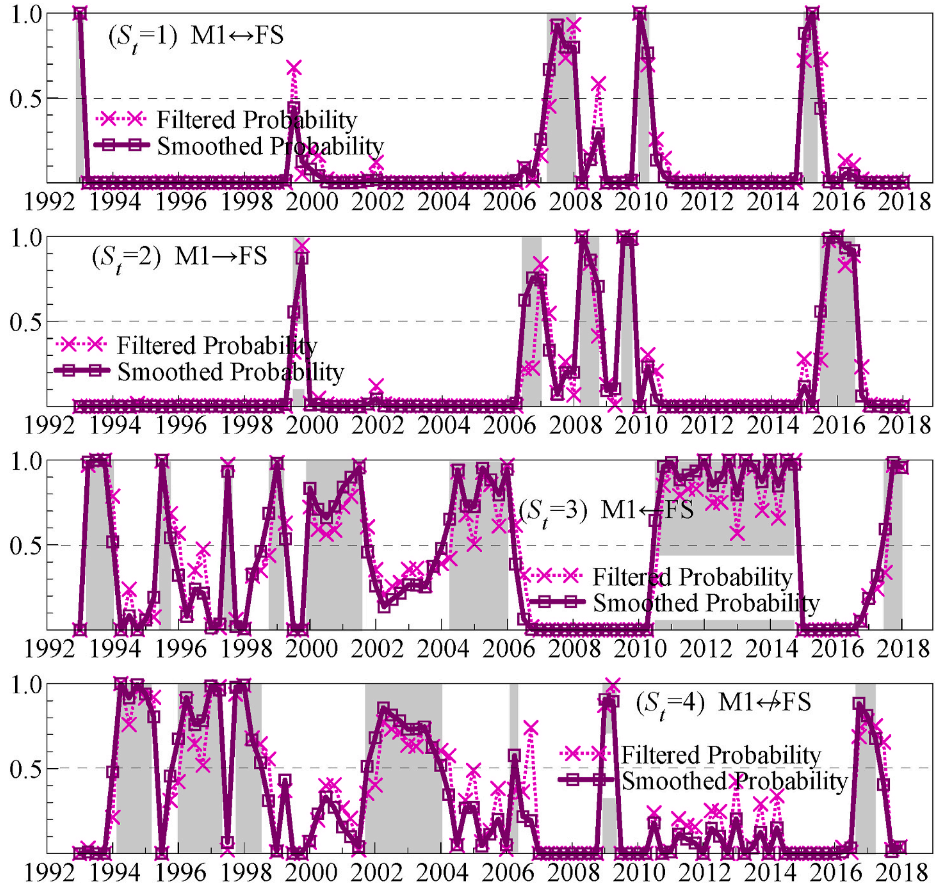

Fig. 4. Probability trajectories of time-varying causal effect between money supply (M1) and financial stability (FS).

development, the effectiveness of price-based monetary policy on output is very limited.

The time-varying causal relationship between market interest rates and prices is illustrated in Fig. 6. State 2 has the longest duration, while the probability of being in State 4 has decreased over time. This suggests that market interest rates and prices have been more correlated in recent years. The price-based monetary policy in general is effective in regulating prices, and has become more responsive to prices as well. Combining the top two panels of Fig. 6, we notice that there is no causality between market interest rates and prices from 1992 to 1995. But during 2012–2018, interest rate had always played a causal role on prices. That is, the effectiveness of price-based monetary policy on price regulation has improved in most recent years. With the rapid development of Internet finance, bank.

deposits shrink substantially due to scale substitution effect and network externality effect. Banks are facing capital shortage problems, causing the demand for funds in the interbank borrowing market to increase, which in turn enhances the sensitivity of interbank lending rates to market interest rates. This ultimately improves the effectiveness of price-based monetary policy instruments.

Fig. 7 presents the states of causal relationship between market interest rates and financial stability. State 2 overwhelmingly dominates the other three states. This implies that market interest rate has a very strong influence on financial stability. In another word, price-based monetary policy is very effective in keeping financial risks under control. This emphasizes the role of price-based monetary policy in helping stabilize financial markets. However, state 3 occurred only shortly in late 1999, 2008 and 2015, indicating that price-based monetary policy does not adjust to changes in financial stability timely. The central bank of China should continue to deepen interest rate reform and liberalization and enhance the interest rate marketization system.

In the following, we calculate the filtered probability $\Pr(S_{2t}|I_t)$ and smoothed probability $\Pr(S_{2t}|I_T)$ to characterize the causal effect trajectory of monetary policies on macroeconomy. Then assess if the central bank's monetary policy stance conforms to the needs of China's macroeconomic development at different historical periods. The top (bottom) panels of Figs. 8–10 illustrate the causal probability trajectory of money supply (interest rate) on output, price, and financial stability, respectively. Similar to Figs. 2–7, the periods with a smoothed probability of 0.5 or greater are shaded to indicate a causal effect.

In early 1990s, Chinese economy was overheated and inflation continued to rise. The central bank adopted a moderately tight monetary policy. Since 1995, the level of inflation began to decline, and macroeconomy successfully achieved a "soft landing" in 1996. For this period, as shown in the top panel of Fig. 8 and the bottom panel of Fig. 9, quantitative monetary policy effectively controlled inflation, and price-based monetary policy effectively kept financial risk in check. In 1997, the Asian financial crisis hit, Chinese

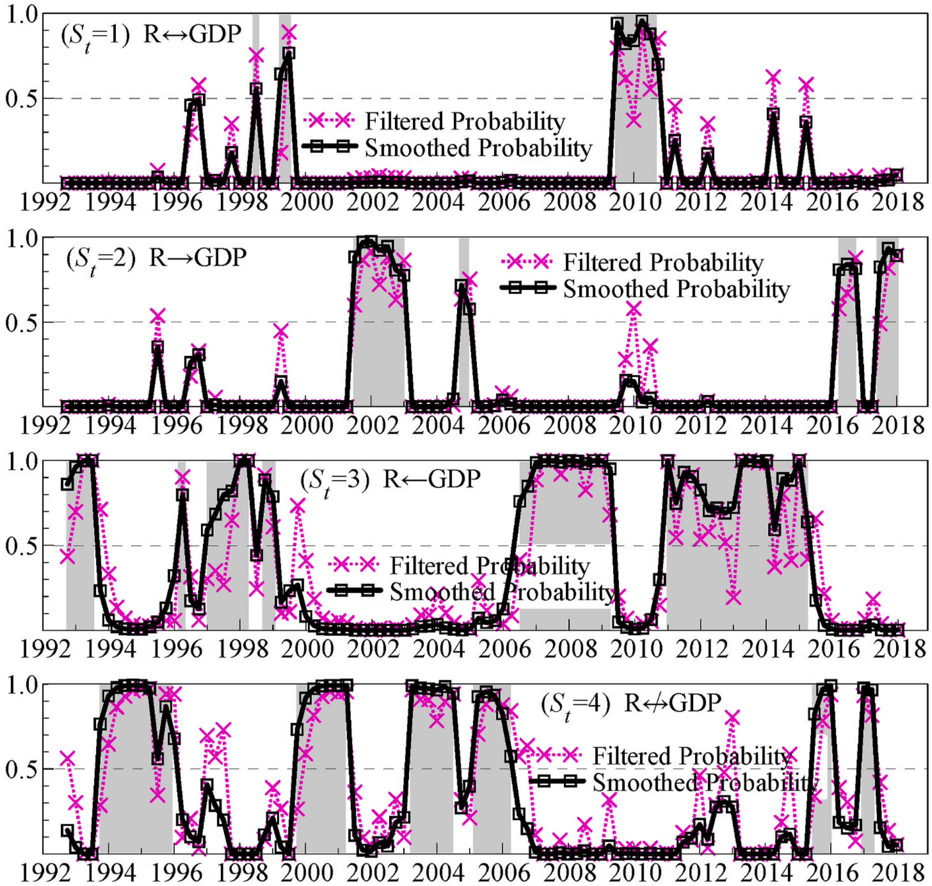

Fig. 5. Probability trajectories of time-varying causal effect between market interest rate (R) and output (GDP).

economy faced continuous downward pressure. The central bank turned to a series of moderately loose monetary policies including expanding bank credit, increasing open market operations, and reducing interest rates significantly. These price-based monetary policies effectively promoted output growth and ensured financial stability during that period as seen in the bottom panels of Figs. 8 and 10.

During the period of 1998–2002, Chinese economy slid into deflation. The central bank adopted a moderately loose monetary policy to fight deflation. As shown in Fig. 9, the price-based monetary policy was effective in stabilizing prices. Subsequently, the market defeated deflation, and Chinese economy entered a growth era in 2003. But problems such as excessive trade surplus, investment overheating in some industries and regions, started to emerge. To prevent big swings in economic growth, the Central Bank of China started to tighten monetary policy in order to maintain price and financial stability, and to keep a moderate output growth at the same time. During 2004–2007, the central bank raised the reserve-deposit ratio and key interest rates multiple times. As shown in Figs. 8–10, over this period of time, both quantitative and price-based monetary policies played an effective role in promoting a steady and moderate output growth, as well as keeping prices and financial markets stable.

When the financial crisis swept the world in 2008, the economic growth rate in China suddenly fell. The central bank immediately implemented a series of easing polices, including cutting the reserve-deposit ratio, the deposit and loan benchmark rates four times, to ensure the liquidity of the banking system and create favorable conditions for firms with lower financing costs. In 2010–2011, inflation was relatively high; excessive liquidity and economic bubble risks emerged. In order to maintain price stability and avoid financial turbulence, the central bank once again implemented a tightened monetary policy. During this two-year period, the central bank raised the reserve-deposit ratio 12 times, and the deposit and lending interest rates five times. The central bank also resumed credit scale control measures to achieve reasonable aggregate quantity of money and credit, and push prices back to stable levels. At the same time, with the intention of maintaining regional financial stability, China signed bilateral currency swap agreements with a number of countries to strengthen bilateral financial cooperation and trade.

In January 2013, China launched Short-term Liquidity Operation (SLO) and Standing Lending Facility (SLF) tools to provide liquidity to the financial system. The central bank removed the floor on bank lending rates in July 2013 and increased the floating range of bank deposit interest rates in 2014. In 2015, the central bank cut the benchmark loan and deposit interest rates three times. On February 26, 2016, the central bank injected liquidity into the market via Medium-term Lending Facility (MLF) and reverse repo. In 2017, the Temporary Liquidity Facility (TLF) operation once again provided temporary liquidity support for commercial banks. During

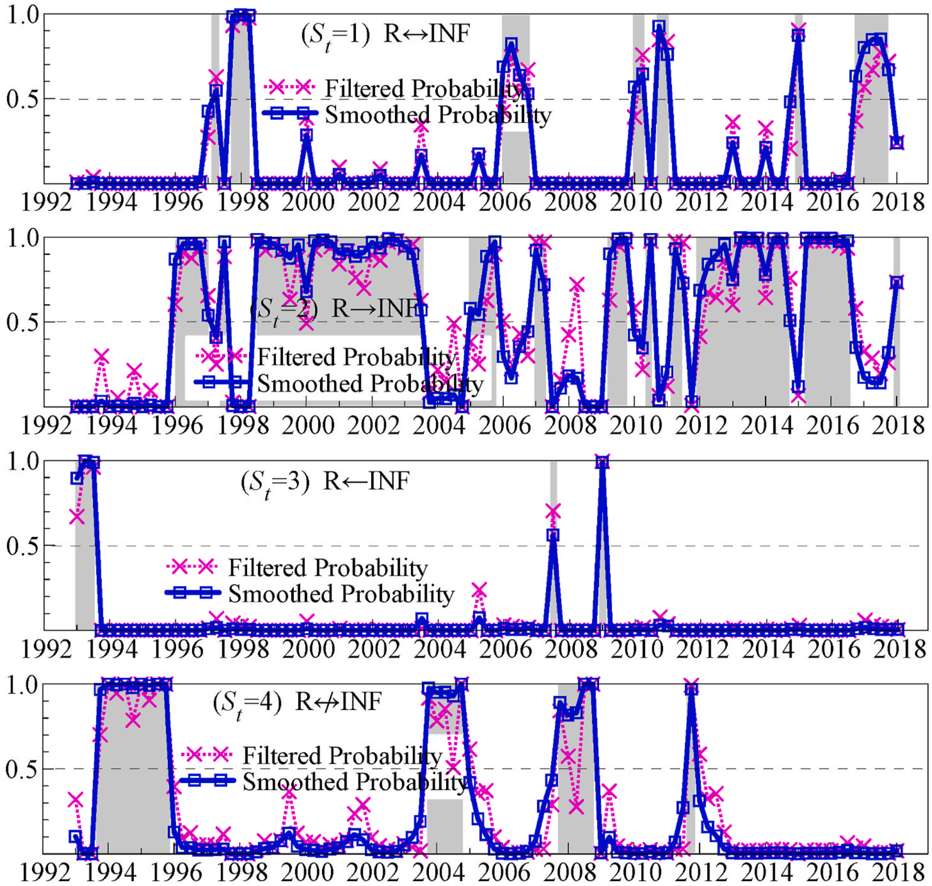

Fig. 6. Probability trajectories of time-varying causal effect between market interest rate (R) and prices (INF).

2013–2017, as shown in Figs. 8 and 9, the quantitative monetary policy has always played a causal role on output, and the Chinese economy started to show upward trend in 2015. However, it is the price-based monetary policy not the quantitative monetary policy that consistently influenced the prices, indicating that the relationship between prices and market interest rate is getting stronger. The price-based monetary policy was more effective in regulating prices during that period. In addition, in the first quarter of 2018, China continued to deepen its interest rate marketization reform, making interest rates a more effective tool as shown in the last segment of the bottom panels in Figs. 8–10.

Notably, as we can see from Figs. 9 and 10, money supply and market interest rate have a complementary effect on prices and financial stability. When a quantitative monetary instrument does not work, the central bank can always find a price-based alternative to be effective, and vice versa. Fig. 8 shows that there are some periods during which both quantitative and price-based monetary policies have no effect on output. A possible explanation is that both money supply and market interest rate have asymmetric effects on output. As Cover (1992) and Karras (1996) show, positive money supply shocks have no or little effect on output, while negative ones have stronger effect on output. In other words, output may only respond to monetary policy changes in one direction, leaving some no-effect periods.

In summary, we reviewed the quantitative and price-based monetary policies implemented by the central bank of China from 1992 to 2018, and confirmed that they were in line with the objective realities of China's macroeconomic development at different historical stages.

5. Nonlinear time-varying dynamic causality measure between macroprudential policy and financial stability

In the post financial crisis era, monetary policy has been questioned for failing to maintain financial stability. Major economies around the world have begun to use macroprudential policy tools. China has also proposed a two-pillar regulatory framework for sound monetary and macroprudential policies. The macroprudential instruments are designed to cope with excess credit expansion, liquidity risks, and sectoral financial risk. This paper discusses the impact of the third class macroprudential instruments on financial stability, and provides some ideas for effective coordination between monetary and macroprudential policies.

Following Angelini et al. (2014), Fendoğlu (2017), Richter et al. (2019), and Grodecka (2020), we choose capital adequacy ratio (CAR), reserve-deposit rate (RR), and loan to value (LTV) as the macroprudential policy proxies for credit, liquidity, and assets,

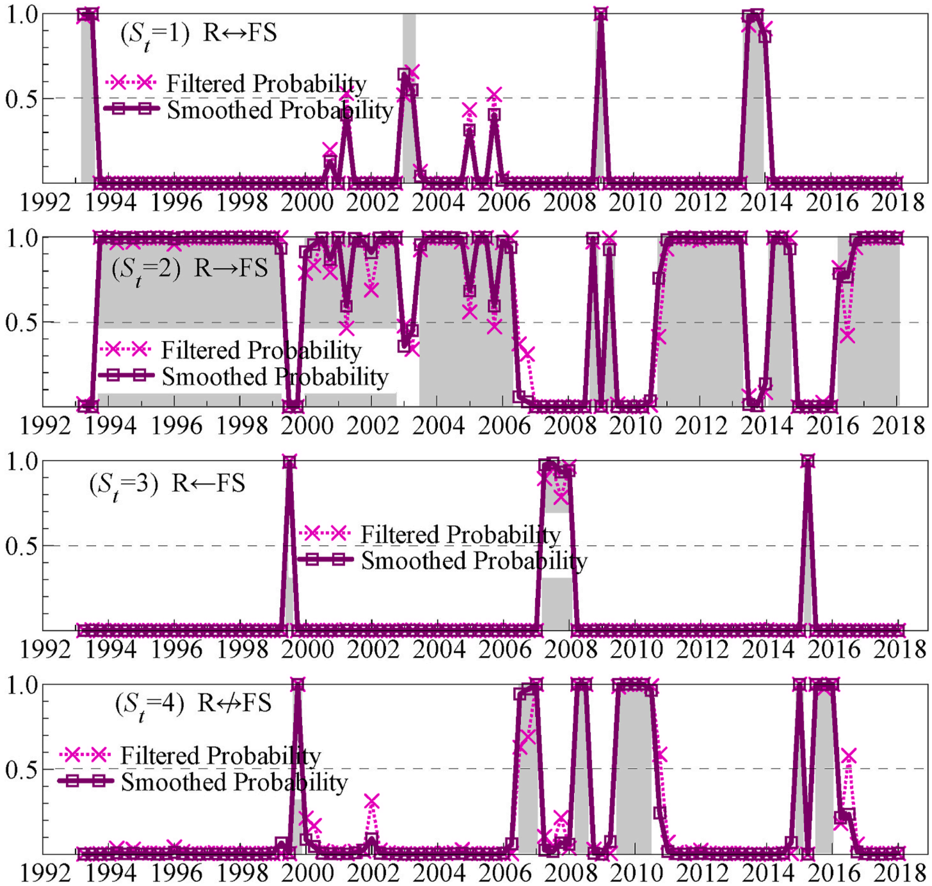

Fig. 7. Probability trajectories of time-varying causal effect between market interest rate (R) and financial stability (FS).

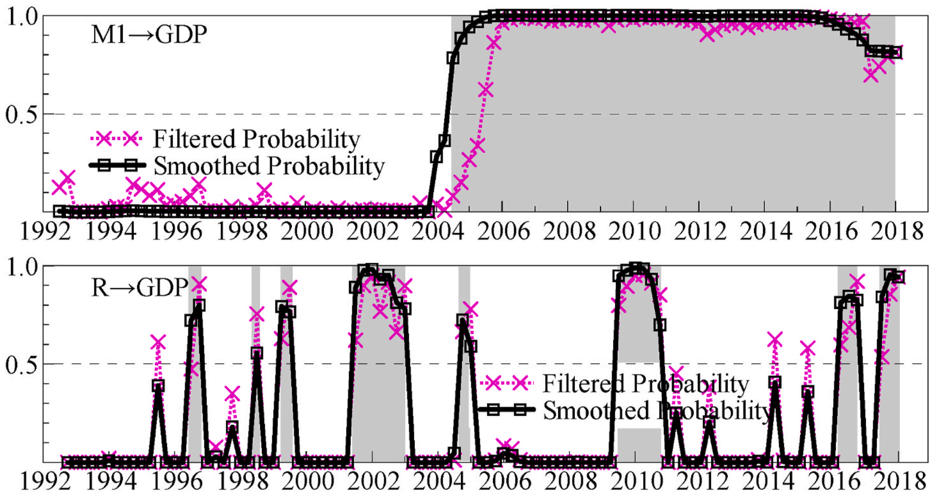

Fig. 8. Causal effect trajectories of monetary policies on output (GDP).

respectively. It should be noted that since the 2008 financial crisis, the adjustment of the statutory deposit reserve ratio not only reflects the change in the central bank's monetary policy, but also usually represents the central bank's intention to regulate and optimize the liquidity structure. Limited by data availability, this section's sample starts from the first quarter of 2010.

To avoid "spurious regression" problems, we test the stationarity of capital adequacy ratio (CAR), reserve-deposit rate (RR) and loan to value (LTV) series using unit root test methods such as ADF, PP and KPSS. Table 5 shows that the CAR, RR and LTV data are all

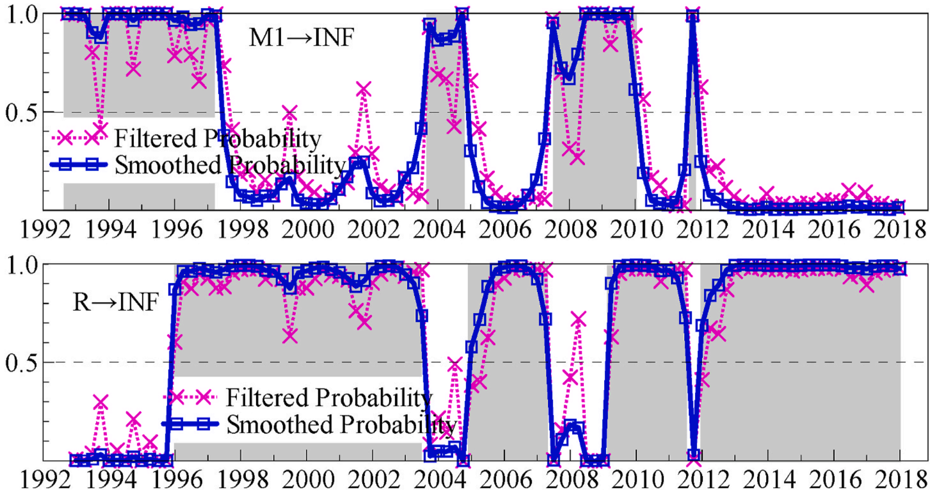

Fig. 9. Causal effect trajectories of monetary policies on prices (INF).

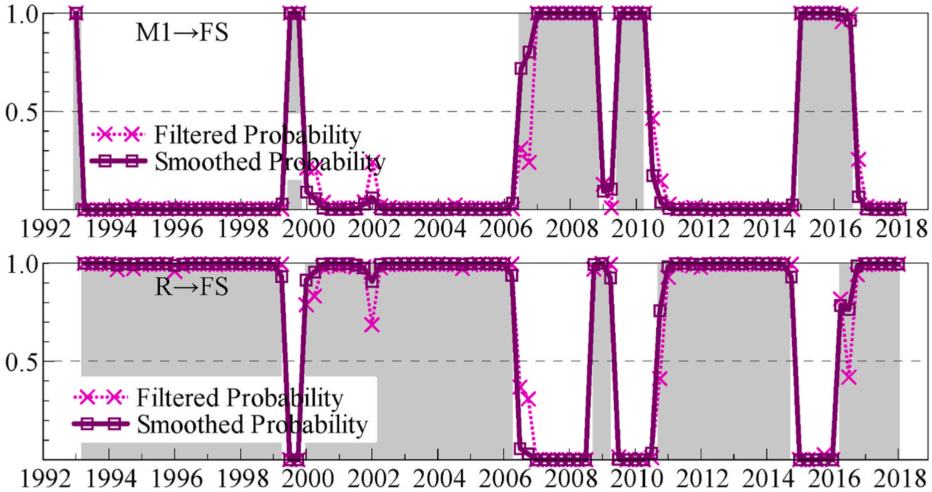

Fig. 10. Causal effect trajectories of monetary policies on financial stability (FS).

Table 5
Unit root test.

Variable	ADF Test	PP Test	KPSS Test	Conclusion
CAR	2.1347	−2.7450	0.6446**	Non-stationary
RR	−3.1367	−2.9787	0.1596**	Non-stationary
LTV	−0.9332	−2.1337	0.4510*	Non-stationary
ΔCAR	−5.5369***	−5.5688***	0.1271	Stationary
ΔRR	−7.9587***	−8.8661***	0.2774	Stationary
ΔLTV	−5.0832***	−6.5298***	0.2632	Stationary

Note: This table shows the unit root testing results for our data series. Δ represents the first-order difference. The null hypothesis of the ADF test and the PP test is that the series is non-stationary, and the alternative hypothesis is that the series is stationary. The null hypothesis of the KPSS test is that the series is stationary, and the alternative hypothesis is that the data is non-stationary. ***, **, and * indicate the rejection of the null hypothesis at the 1%, 5% and 10% significance levels, respectively.

non-stationary at the 10% or 5% level. After taking first difference, these series become stationary at the 1% level. That is, they are cointegrated to the order of one, or I (1).

As shown in Table 6, to explore the cointegration relationship between capital adequacy ratio (CAR), reserve-deposit rate (RR), loan to value (LTV) and financial stability (FS), the minimum AIC and SIC values are obtained when $p = 2$, $p = 1$, and $p = 1$, respectively. Table 6 also shows the results of boundary cointegration test. The F statistics of all Bounds tests is greater than the bound

Table 6
Boundary cointegration test.

Variables	Lags	F-statistic	Test Threshold		
			P	I (0)	I (1)
(CAR,FS)	2	4.6225**	10%	2.44	3.28
(RR,FS)	1	4.1380**	5%	3.15	4.11
(LTV,FS)	1	4.7053**	1%	4.81	6.02

Note: This table shows the boundary cointegration test results. Please refer to Table CI (i) in Pesaran et al. (2001) for the thresholds. ** indicate the rejection of the null hypothesis of no integration relationship at 5% significance levels, respectively.

Table 7
Causality relationship between macroprudential policy and financial stability.

Parameter	CAR—FS	RR—FS	LTV—FS	Parameter	CAR—FS	RR—FS	LTV—FS
p_{11}	0.8350*** (0.1241)	0.9175*** (0.0588)	0.4914** (0.2018)	q_{11}	0.9089*** (0.0634)	0.7757*** (0.1789)	0.8543*** (0.0843)
p_{00}	0.9200*** (0.0564)	0.8516*** (0.1117)	0.8856*** (0.0650)	q_{00}	0.7576*** (0.1364)	0.9644*** (0.0356)	0.5341*** (0.1842)
μ_{10}	0.1319*** (0.0465)	0.2355 (0.8289)	−0.5737 (1.3490)	μ_{20}	−0.0112 (0.0848)	−0.0107 (0.0132)	0.1568** (0.0640)
μ_{11}	0.5850*** (0.0489)	−0.3151 (0.8307)	0.5284 (1.3479)	μ_{21}	0.0006 (0.0841)	0.7268*** (0.0910)	0.1753*** (0.0633)
φ_1	−0.7647*** (0.0474)	−0.0484** (0.0221)	−0.1828*** (0.0016)	φ_2	0.0251*** (0.0065)	−0.3007*** (0.0626)	0.0011* (0.0006)
$\alpha_{10}^{(1)}$	0.2524 (0.1677)	−0.3755 (0.3065)	0.0026 (0.2095)	$\alpha_{20}^{(1)}$	0.3288 (0.3467)	0.3711*** (0.13845)	1.6022*** (0.3473)
$\alpha_{10}^{(2)}$	−0.4037** (0.1690)	——	——	$\alpha_{20}^{(2)}$	0.3361 (0.3550)	——	——
$\alpha_{11}^{(1)}$	0.5396*** (0.1719)	0.7418** (0.3165)	−0.8364*** (0.2094)	$\alpha_{21}^{(1)}$	−0.1325 (0.3501)	−0.3917 (0.2429)	1.9900*** (0.3474)
$\alpha_{11}^{(2)}$	0.2104 (0.1688)	——	——	$\alpha_{21}^{(2)}$	−0.2388 (0.3653)	——	——
$\beta_1^{(1)}$	−1.1038** (0.4528)	−1.6770*** (0.3157)	−0.2775*** (0.0540)	$\beta_2^{(1)}$	−0.0324*** (0.0125)	0.2399*** (0.0291)	0.0022* (0.0013)
$\beta_1^{(2)}$	−1.9163*** (0.2958)	——	——	$\beta_2^{(2)}$	−0.0331*** (0.0124)	——	——
σ_{11}	0.0571*** (0.0145)	0.1357*** (0.0222)	0.0185*** (0.0044)	σ_{21}	0.0184*** (0.0029)	0.0503*** (0.0160)	0.0399*** (0.0063)
σ_{10}	0.1865*** (0.0279)	2.5586*** (0.5693)	6.9608*** (1.0610)	σ_{20}	0.2771*** (0.0706)	0.0574*** (0.0080)	0.1613*** (0.0355)

Note: This table reports the parameter estimates for the nonlinear time-varying dynamic causality relationship between macroprudential policy variables (CAR, RR, LTV) and financial stability (FS). ***, **, and * indicate statistical significance at the 1%, 5%, and 10%, respectively. The values in parentheses are the standard deviations of the corresponding parameter estimates.

of the 5% threshold, indicating a rejection of the null hypothesis. That is, there is a cointegration relationship between each pair of the macroprudential policy variables (CAR, RR, LTV) and financial stability (FS).

As mentioned earlier, traditional linear vector error correction models can only identify the "static" linear relationship between two variables. But due to frequent changes in external environment and shocks to the economy, we expect that the causal relationship between macroprudential policy and financial stability change over time. Thus, we use the proposed nonlinear MSC-VEC model to identify the time-varying dynamic causal link between macroprudential policy and financial stability.

Table 7 present the parameter estimates of our MSC-VEC model. p_{11} and p_{00} are the probabilities of financial stability maintaining the same response or no response to macroprudential policy, respectively; q_{11} and q_{00} are the probabilities of macroprudential policy maintaining the same regulating effect or no effect on financial stability, respectively; $\mu_{10}, \mu_{11}, \mu_{20}$ and μ_{21} are the constant estimates of the macroprudential policy-financial stability system; φ_1 is the coefficient of the error correction term of the macroprudential policy variable; φ_2 is the coefficient of the error correction term of the financial stability; α_{10} and α_{11} are the autoregressive coefficients of the macroprudential policy variable; α_{20} and α_{21} are the autoregressive coefficients of the financial stability; β_1 and β_2 are the causal coefficients between macroprudential policy and financial stability.

The parameter estimates for the nonlinear time-varying dynamic causality relationship between the macroprudential policy variables and financial stability are shown in Table 7. The estimates of p_{11}, p_{00}, q_{11} and q_{00} are all significant at the 1% level. The error correction coefficients of macroprudential policy variables and financial stability have opposite signs or both negative signs, confirming their cointegration relationship. The β_1 and β_2 coefficients in Table 7 uncover the causal effect of macroprudential policy on financial stability. The coefficient of CAR on financial stability is significantly negative, and the coefficients of RR, LTV on financial stability are positive and statistically significant, meaning that increasing CAR and decreasing RR, LTV can help maintain financial stability. This is because increasing the capital adequacy ratio can help protect the interests of creditors, restrict unreasonable asset

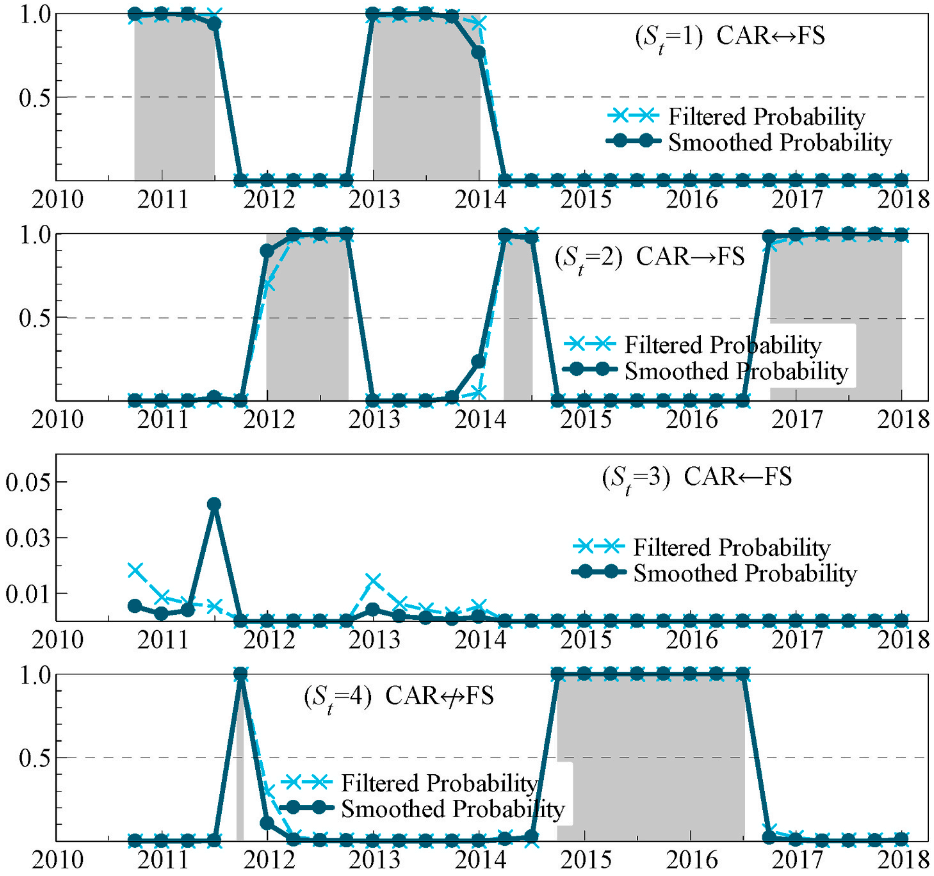

Fig. 11. Probability trajectories of time-varying causal effect between capital adequacy ratio (CAR) and financial stability (FS).

expansion, and control bank risks, and in turn maintain the stability of the financial system. The reduction of the statutory deposit reserve ratio for the purpose of targeted regulation can optimize the liquidity structure. While the total liquidity of the banking system is basically stable, it will guide the healthy growth of monetary credit and social financing, and create suitable monetary and financial environment, and consequently lead to a stable financial system. Reducing the loan-to-value ratio is the key to curbing the inflation of asset price bubbles such as real estate, stocks and bonds, and an important macroprudential policy tool for maintaining financial stability.

Conversely, the coefficients of financial stability on CAR, RR and LTV are negative and statistically significant, indicating that a decrease in financial stability would lead the central bank to implement macroprudential liquidity and asset tools. This is consistent with the "leaning against the wind" operational characteristics of macroprudential policy, which is similar to that of monetary policy. However, due to the procyclicality of regulatory capital, commercial banks tend to make procyclical adjustments to their capital adequacy ratios. They choose to lower their capital adequacy ratios during economic downturns, which is usually accompanied by the instability of the financial sector. Therefore, the capital adequacy ratio is lower during the period when financial stability is endangered.

The causality between macroprudential policy and financial stability may be affected by the macroeconomic cycle and financial cycle. To account for this, we calculate the filtered probability $\Pr(S_t|I_t)$ and smoothed probability $\Pr(S_t|I_T)$ of the causal relationship over the entire sample period. The pairwise filtered probability and smoothed probability trajectories between macroprudential policy variables and financial stability are depicted in Figs. 11–13. In the figures, $S_t = 1$ represents the state when there is a bi-directional causal effect between macroprudential policy and financial stability; $S_t = 2$ represents the state when only macroprudential policy has a causal effect on financial stability; $S_t = 3$ represents the state when only financial stability has a causal effect on macroprudential policy; $S_t = 4$ represents the state when there is no causal relationship. Note that the filtered probability $\Pr(S_t|I_t)$ is calculated based on the information obtained during t period, while the smoothed probability $\Pr(S_t|I_T)$ is based on the information set of the entire T sample period. Thus, the latter can discern the time-varying dynamic causal relationship more accurately. Based on smoothed probability calculations, the periods when there is a causal effect are shaded.

Figs. 11–13 depicts the probability trajectories of time-varying causal effect between macroprudential policy tools and financial stability. As far as macroprudential credit-based tools are concerned, as shown in Fig. 11, state 2 has the longest duration and occurs more often, indicating that credit tools have been effective in helping financial system run smoothly, especially during the period of

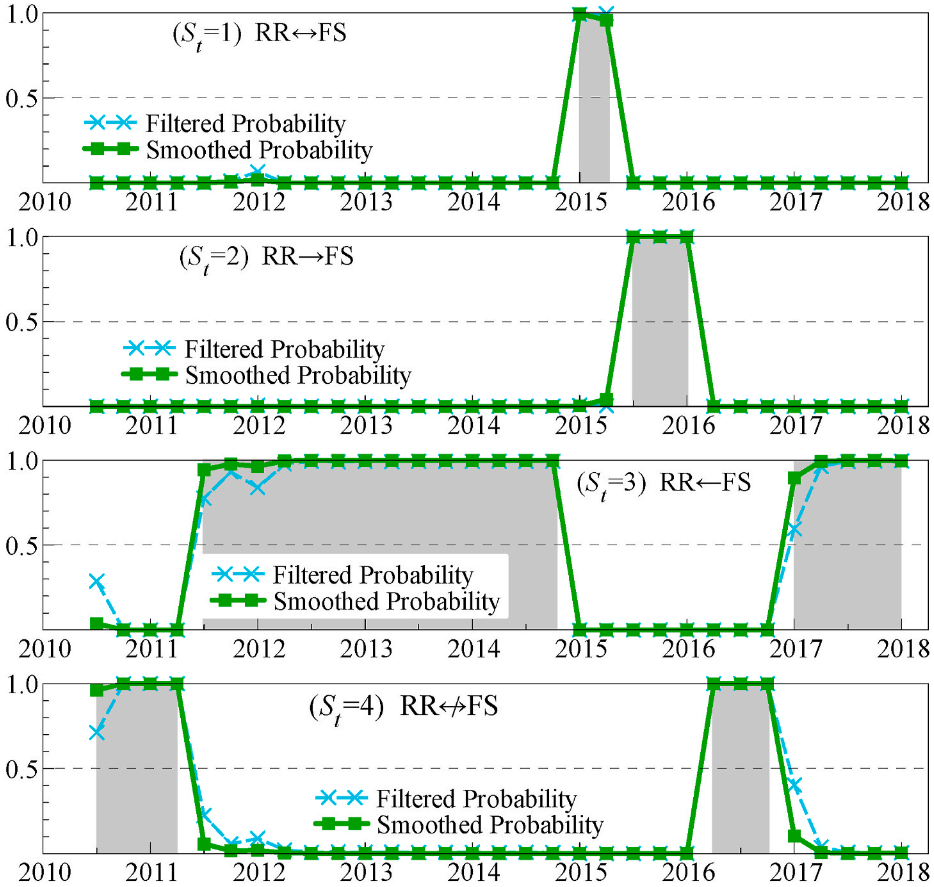

Fig. 12. Probability trajectories of time-varying causal effect between reserve-deposit rate (RR) and financial stability (FS).

2016–2018. There is a bi-directional casual effect between macroprudential policy and financial stability only in early 2010s as indicated by the shaded area of state 1. The probability of being in state 3 is always low, meaning that credit tools have not been unidirectionally responsive to financial uncertainty. In view of the effectiveness of credit tools, the central bank should attempt to use credit tools more often, so they can be more responsive to deterioration in financial stability.

The causal relationship between reserve deposit rate (proxy for macroprudential liquidity policy tools) and financial stability is shown in Fig. 12. The duration for regime $S_t = 1$ is very short, indicating that the bi-directional interaction between liquidity tools and financial stability is rare. The probability of being in state $S_t = 2$ is high only around 2016, that is, liquidity policy tool only has some limited regulatory effect on financial stability. State $S_t = 3$ has the longest duration, meaning that central bank of China tends to respond to financial stability risk using macroprudential liquidity tools.

Fig. 13 shows the causal relationship between macroprudential asset tool (proxied by loan to value) and financial stability. State $S_t = 2$ has the longest duration, while the other three states all have very short durations. This means that asset-based instruments have been effective in regulating the stability of the financial sector. More effective than liquidity tools through the reverse feedback mechanism, asset-based tools should shoulder the responsibility of maintaining the smooth operation of the financial system. However, asset tools are not very responsive to, and have not made timely adjustments in accordance with financial stability. China should continue to promote macroprudential policies, especially pay more attention to asset-based tools, and further improve the two-pillar regulatory framework of monetary policy and macroprudential policies.

In the following, we calculate the filtered probability $\Pr(S_{2t}|I_t)$ and smoothed probability $\Pr(S_{2t}|I_T)$ to characterize the regulatory effect of macroprudential policies on financial stability. The three panels of Fig. 14 illustrate the effectiveness of CAR, RR and LTV on financial stability, respectively. Similar to the previous figures, the periods with a smoothed probability of 0.5 or greater are shaded to indicate a causal effect. Fig. 14 shows that macroprudential policies can effectively act on financial stability, and there is a complementary effect between credit, liquidity, and asset-based macroprudential policy tools. The overall effectiveness of these macroprudential tools covers almost the entire sample period. In comparison, the effectiveness of credit- and asset-based tools is higher than that of liquidity-based tools.

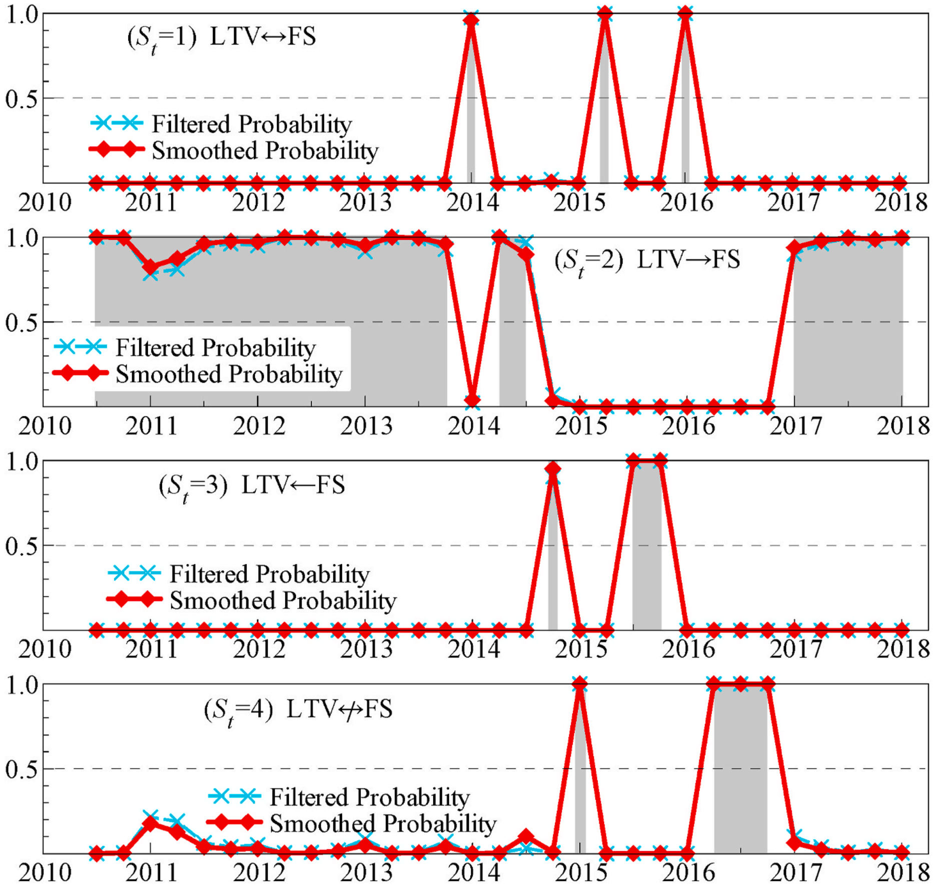

Fig. 13. Probability trajectories of time-varying causal effect between loan to value (LTV) and financial stability (FS).

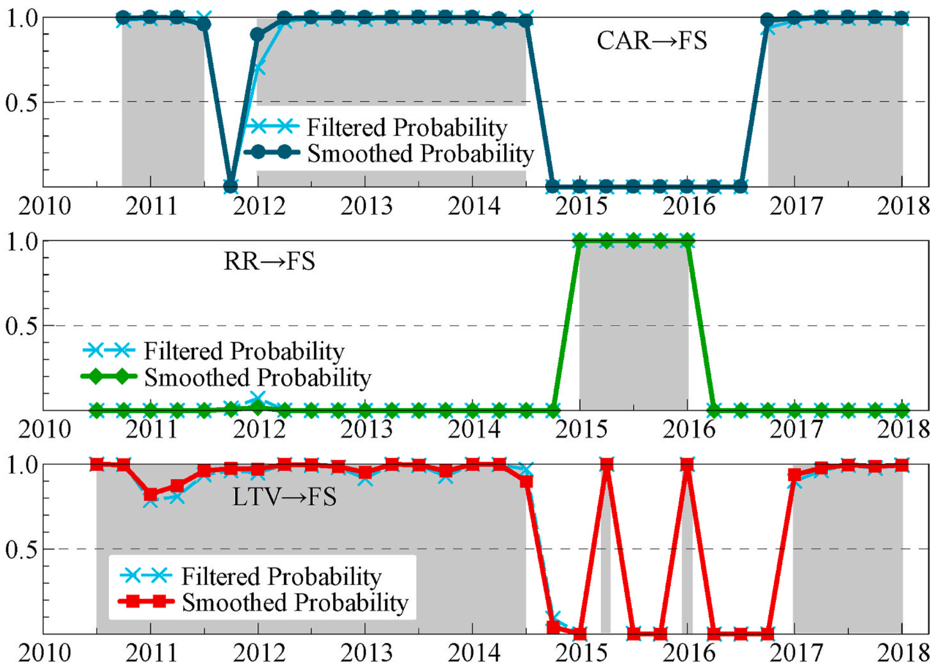

Fig. 14. Causal effect trajectories of macroprudential policies on financial stability (FS).

6. Conclusion

This paper uses a nonlinear MSC-VEC model to examine the dynamic causal relationship between monetary policies and macroeconomy, macroprudential policies and financial stability in China. Our model characterizes the time-varying features of parameters based on the states defined directly in terms of the causal relationship between monetary variables and macroeconomic variables, macroprudential policy variables and financial stability. We are able to identify when changes in causality might have occurred and connect those changes with the actual monetary and macroeconomic events.

We find that expansionary quantitative monetary policy is conducive to promoting output growth, while tightening quantitative monetary policy can help maintain price stability and financial stability. Expanding price-based monetary policy is helpful in promoting output growth and ensuring financial stability. Tightening price-based monetary policy can stabilize prices effectively. The central bank implements a tightening monetary policy when facing an increase in output and price levels, and vice versa. During times of financial turbulence, the central bank implements expansionary quantitative monetary policy or tightening price-based monetary policy, and vice versa. More than that, macroprudential policy can also effectively work on financial stability.

We also find that the effects of quantitative monetary policy and price-based monetary policy are complementary on prices and financial stability. As a well-functioning and stable financial system is crucial to the health of a country's real economy, we should consider maintaining financial stability as one of the major objectives of monetary policies in addition to promoting output growth and stabilizing prices. The complementary effect suggests that, to maintain price and financial stability, central banks should implement a hybrid or mixed monetary policy instead of using only quantitative or price-based instruments.

We further recommend that macroprudential policy should be used in conjunction with monetary policy to maintain financial stability. The credit- and asset-based macroprudential policy tools are more effective than the liquidity tools, but they are highly complementary to each other and should be considered from a holistic perspective.

Author statement

We all (the authors) have seen and approved the final version of the manuscript being submitted. This article is our original work and has not received prior publication and is not under consideration for publication elsewhere.

We declare that we have no known competing financial interests or personal relationships that could have appeared to influence the work presented in this paper.

Acknowledgments

The authors acknowledge the support from the National Natural Science Foundation of China (No. 71573104). Any errors that may remain are the authors' responsibility.

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