Price rigidity, heterogeneous expectations and the dynamics of inflation

批注 [C1]: 请主要查看内容，公式、图表会在后期插入，格式和版式后期将统一加工处理。

DENG Yanfei

School of Economics, East China Normal University

DONG Feng

Antai College of Economics and Management, Shanghai Jiao Tong University

XU Yingfeng

Department of Economics, Faculty of Arts, University of Alberta

FENG Wenwei

School of Economics at, Faculty of Economics and Management, East China Normal University

Management World

11-1235/F

1002-5502

2017

09

sticky information

sticky price

dual stickiness

hybrid New Keynesian models

heterogeneous expectations

1 Introduction

Nominal and real rigidities are among the four most significant features of the New Keynesian model.① This paper mainly discusses price rigidity under nominal rigidity② (problems concerning real rigidity such as the strategic complementarity and ~~cost-plus~~ pricing will also be appropriately mentioned as needed). It means that some companies can adjust to the optimal price in time, and some companies keep the price

unchanged for various reasons. At the end of the 20th century, thanks to Taylor (1980), Rotemberg (1982), Calvo (1983), McCallum (1997), and Clarida et al. (1999), the New Keynes-Phillips curve, which was derived from the traditional sticky price theory and described the impact of aggregate demand on output and inflation, like the classic physics at the end of the 19th century, seems to have been perfectly constructed. Whereas, some scholars have gradually realized its three drawbacks: (1) The pre-announced trustworthy inflation-inhibiting policy will lead to the strange result that prices continue to rise (Ball, 1994); (2) it does not explain inflation inertia well (Fuhrer and Moore, 1995); and (3) it fails to demonstrate why monetary policy shocks have a lagging and gradual impact on inflation (Mankiw, 2001). The root cause of these problems is almost always in the sticky price model: the price level is sticky, but the inflation rate can change rapidly (Mankiw and Reis, 2002).

Mankiw and Reis (2002) proceeded from the micro-foundation of the traditional sticky price theory, and proposed sticky information theory based on the assumption that the information of the macroeconomic environment spreads slowly among the masses due to the generation of cost when the economic entity obtains and analyzes the information. In this paper where the sticky information model is an alternative to the sticky price model, the authors compared the two models. The results show that the sticky information model has a better description of the real economic characteristics. In theory, it can better represent three widely-recognized effects of monetary policy: first, the suppression of inflation will always lead to economic contraction; second, the impact of monetary policy follows a hump-shaped pattern; and third, inflation is pro-cyclical. Then, they extended the model to the general equilibrium framework (Mankiw and Reis, 2007), and specifically discussed the micro-foundation of the sticky information model in household and corporate sectors (Reis, 2006a, 2006b). Further, Reis (2009) used the general equilibrium model of sticky information for monetary policy analysis. So far, the sticky information model has been fully developed.

According to the Phillips curve, the source of the sticky price theory and the sticky information theory, the former is about forward-looking expectation, while the latter is about lagged expectation (but both are homogenous expectation models). Such research topics as how expectations are formed and passed on are still interesting and challenging. Xu, Fan and Xue (2015) constructed the DSGE model with heterogeneous expectations, which is of policy analysis significance. Their research is based on the research results of Branch and McGough (2009): when the expectation operator meets certain condition of axiom, the heterogeneity of expectations is only the simple addition of the rational expectations and the adaptive expectations. However, it should be pointed out that the sticky price model modified by Christiano et al. (2005) (i.e., hybrid New Keynes) is consistent in thought with the heterogeneous expectation model described above (both are forward-looking rational expectations plus backward-looking adaptive expectations) and it is more researcher-friendly (the difference is that the former is about the ~~public~~ while the latter is about the ~~business~~). Through comparative analysis of these three models in a standard DSGE framework,

Trabandt (2009) found that the sticky information model and the hybrid New Keynesian model have highly consistent function in explaining the effects of monetary policy.

Dupor et al. (2010) proposed another heterogeneous expectation model, the dual stickiness model, which can be parallel to the New Keynesian model. With empirical analysis of US data and a comparison of the impulse responses of inflation and output under the two models, the dual stickiness model is preferable. The dual stickiness model is a nested structure. Its advantage is that this compound model can be transformed into a simple sticky price model and a sticky information model by assigning some parameter zero. However, its disadvantage is that the exogenous nest is inevitably stiff, lacking (not without) micro-foundation and internal logical consistency. Therefore, this paper proposes a theoretical concept of systematically implanting sticky information and sticky price mechanisms into the DSGE model. The key is to assume that the final product manufacturers and the intermediate product manufacturers are both monopolistic, though usually one is assumed to be monopolistic, and the other is assumed to be completely competition-driven. The following are what this paper aims to answer: What are the sticky characteristics of the ~~corporate~~ sectors in China's market economy? Or how sticky they are? Is dual stickiness also reflected in China's economic data? Is the dual stickiness model different from the hybrid New Keynesian model? Which model should be chosen when such ~~thing~~s as optimal monetary policy are considered? At present, Chinese scholars only have limited research in these areas (Wang, 2009; Peng, 2011; Wang, Zhang and Liu, 2012), and have not done any comparative analysis of the models within a unified framework in the Chinese context.

This paper follows the two-step method by Duporet al. (2010) and uses the macro data of China (Chang et al., 2015) for estimation, which was carefully studied and rigorously dealt with. This paper finds that the dual stickiness model and hybrid New Keynesian model (heterogeneous expectation models) fit better than the sticky information model and the sticky price model (homogenous expectation models). Among them, the sticky information model fits the worst. Furthermore, in each model, the corresponding sticky parameters are significantly different from zero, which indicates that the corporate sectors in the Chinese market are featured with both sticky information and sticky price, both of which are related to China's inflation. It is estimated that under the dual stickiness model, the firms adjust prices every five quarters and use the latest information to determine prices every 7.7 quarters on average, and that under the hybrid model, 72 percent of the firms are forward-looking while 28 percent are backward-looking. Xu, Fan and Xue (2015) predicted that the proportion of the public's backward-looking adaptive expectation is about 80%, which is quite different from the above proportion. The difference is that they also include the household sector in their estimates; while this paper only focuses on the ~~corporate~~ sector. For the ~~corporate~~ sector alone, a profitable organization with relatively complete sectors and functions, it is reasonable to believe that the ratio of adaptive expectations to rational expectations is close to 3:7. Additionally, compared

with the hybrid New Keynesian model, the dual stickiness model also includes lagged expectation term, with its corresponding estimated parameters apparently different from zero. Based on these two heterogeneous expectation models, this paper simulates the impulse responses of the models to the ~~impacts~~ of monetary policy and natural rate by increasing the variables of inflation, general price level and output on the basis of the ~~cost-plus impact~~ proposed by Dupor et al. (2010). Then, it is easily found that there is a significant difference between the two models under the ~~instant impact~~, although the dynamic paths of them are very similar under ~~sustained impacts~~. Further, with the dual stickiness nested into the hybrid New Keynesian model, empirical results tend to match the hybrid New Keynesian model.

The following sections of this paper are organized as follows: Section two briefly reviews and compares the main equations and economic implications of the sticky price and sticky information models as well as those of the dual stickiness model and the hybrid New Keynesian model; Section three uses China's relevant data from 1996 Q1 to 2014 Q2 to estimate the above four models in a consistence analytic framework; Section four further compares the dual stickiness model and the hybrid New Keynesian model; and the final session is a summary. In addition, this paper has formed the theoretical proposal that sticky information mechanism and sticky price mechanism being implanted into the DSGE model, and relevant information is available upon request.

2 Review and comparison of the models

2.1 Homogeneous expectations: sticky price model and sticky information model

Mankiw and Reis (2002) used a similar set of equations to demonstrate the characteristics of the sticky price model and the sticky information model. They assume that no matter which model it is, there is always a certain functional relationship between the ideal real price level ($pt^* - pt$) determined by the firm and the output gap (yt) ③ (the logarithmic forms of nominal variables such as price and output are represented by lowercase letters, the same below), and the sensitivity of the two dependent variables is α, which ~~tat~~ is

. The following are the optimal pricing equations for the two models:

. The current adjusted price under the sticky price model is displayed on the left, and q_t is the weighted average of the ideal price for the current and future periods of the company; the right side is the adjusted price under the sticky information model when the company updates its latest information (before period k). To keep similar expressions to the dual stickiness model and the hybrid New Keynesian model to be described below, this paper makes a slight change based on Mankiw and Reis (2002) and assumes γ as the probability of stickiness when each firm does not adjust the price. In accordance with the law of large numbers, the proportion of companies that will adjust the price in each period is $1 - \gamma$. Similar assumptions are made in the sticky

information model; the difference is that all companies will adjust prices for each period, but only $(1-\varphi)$ percent of the companies will update the information.

Therefore, the total price level of the two models is:

The sticky price model employs the pricing structure of Calvo (1983); and the equation for total price level is from a standard price relation in the Dynamic New Keynesian (DNK) model: $P_t = (\int_0^1 P_{it}^{(1-\varepsilon)} di)^{1/(1-\varepsilon)}$. According to relevant assumptions, after logarithmic linear approximation, it becomes $p_t = (1-\gamma)q_t + \gamma p_{t-1}$. The sticky information model combines time-dependent random pric-setting adjustment rule of Calvo (1983) and the imperfect information assumption of Lucas (1972); it is derived from the contract model of Fishcer (1977) or something similar to the pricing model with one-order lag of Rotem-Berg and Woodford (1997).

With simple algebra calculation, New Keynesian Phillips curve and sticky information Phillips curve can be deducted easily.

It is easy to distinguish the similarities and differences of the two models: the sameness is that their current inflation (π_t) is both related to their current output gaps (y_t); the difference is that under the mechanism of sticky price, the current inflation is decided by the expected inflation ($E_t\pi_{t+1}$), while under the mechanism of sticky price, the current inflation is the outcome of the lagged influence of previous inflation on current inflation (π_t) and the output gap variation (Δy_t). In addition, the two models also imply the major difference in the relationship between monetary policy and output growth. The former indicates that permanent monetary expansion policies can bring permanent growth in output, which does not match the natural rate hypothesis (Lucas, 1972), and was criticized by McCallum (1998). However, the latter excludes this kind of possibility; that is when, $p_t = E_{t-k}p_t$,it must be $y_t = 0$

2.2 Heterogeneous expectations: dual stickiness model and hybrid New Keynesian model

Gali and Gertler (1999) and Gal íet al. (2005) found in empirical studies that lagged inflation is an important part of the New Keynesian Phillips curve. Then, Christiano et al. (2005) added lagged inflation into the traditional sticky pricing mechanism in accordance with the rule of thumb, overcoming the shortcomings of the traditional sticky pricing mechanism in empirical studies from the perspective of adaptive expectations. Dupor et al. (2010) considered this model to be the most powerful competitor of the dual stickiness model. In order to compare the similarities and differences between the two, they established a similar analytical framework. After logarithmic linearization, the total price index with a structural consistency and the sticky pricing equation after simplification (subjective discount factor being 1, and the ~~cost plus~~ being about 1) are as follows:

Parameter p_f^t represents the pricing of sticky price with complete information; mc^n stands for the logarithmic nominal marginal cost minus the marginal cost under the influence of logarithmic natural rate, that is, the percentage of the deviation of the nominal marginal cost from the steady state, which can be called the deviation ratio of nominal marginal cost, or the gap of the nominal marginal cost logarithmically. The key assumption of the dual stickiness model is that the company adjusts the price with a probability of $(1 - \gamma)$, in which a probability of $(1 - \varphi)$ occurs because of information updating. The equation is as follows under the rule of large numbers:

The adjusted sticky price model (i.e., hybrid New Keynesian model) assumes that ω percent of companies will consider the inflation of the previous period, and will display pricing behaviors with backward-looking adaptive expectations (p_t^b). Through calculation, two inflation equations (i.e., the total supply equation) are obtained:

The superscript *D* corresponds to the dual stickiness model, and *H* corresponds to the hybrid New Keynesian model; ρ, ζ_1 and ζ_2 are recombination coefficients, which are relatively lengthy and complicated. The deep parameters are not the focus of this article, so will not be discussed here (Dupor et al., 2010). It is not difficult to find that the dual stickiness model also includes a lagged expectation term which does not exist in the hybrid New Keynesian model. Although they both contain lagged inflation (ρ indicates the degree of inflation inertia), the former is endogenous under rational expectations, while the latter is exogenous for adaptive expectations (which can be simply understood as that in the standard New Keynes-Phillips curve, $E_{tt}\pi_{tt+1} = \pi_{tt-1}$). For the hybrid New Keynesian model, ζ_1^H is the cost of inflation inhibition; for the conventional quarterly data, when ρ^{HH} is close to 1, the cost can be understood as: if the annual inflation rate is to fall by 1%, the actual output should be lower than potential output by $1(/16\zeta_1^H)$ percentage points.

3 Chinese sticky characteristics under estimation models

In the above two inflation equations, the parameters to be estimated include γ, the ratio of companies that do not change the price, φ, the ratio of companies that change the price but do not update the information, as well as ω, the ratio of backward-looking pricing behavior. The nested model developed by Dupor et al. (2010) is useful in that it can still be employed for the estimation of pure sticky information model ($\gamma = 0$) or pure sticky price model ($\varphi = 0$). Therefore, based on the statistical significance of the structural parameters, the above models can be used for comparison with the fitting of China's data.

The sticky information model is difficult to calculation due to its indefinite lagged expectation term. Mankiw and Reis (2006) proposed a method for solving the model. However, the solution proposed by Meyer-Gohde (2010) had an absolute advantage in the speed and accuracy of calculation, so it was well-received by Reis. The structure of the dual stickiness model is even more complicated. Here the two-step method used Dupor (2010) is adopted to evaluate the above four models. The first step is to

perform vector autoregression (VAR) to get the gap of the real marginal cost and to the sequence of inflation forecasts; on this basis, the second step minimizes the gap between the theoretical value and the true inflation data. The complete process of data processing and estimation fitting has been compiled into the matlab program.④

Based on the availability of data and the conventional practices of such models, China's data from the first quarter of 1996 to the second quarter of 2014 are adopted for empirical analysis. Chang et al. (2015) carefully studied and recalculated the sequence of China's macro data (all quarterly data go through seasonal adjustement), which cover the raw data sequences can be used in this article, such as Consumer Price Index (*CPI*), Retail Price Index (*RPI*), GDP deflator (*GDP-def*), labor income share (*s*) and logarithmic real GDP calculated respectively with the expenditure method and the production method. These six groups of data are mainly for two purposes. The first three columns can be used to get the inflation rate by calculating the link relative ratio and logarithmic difference, and labor income share can be directly used as the proxy variable of real marginal cost gap. The last two groups can be employed to obtain output gap, which can be used as the proxy variable of the real marginal cost gap through quadratic detrending (QD) or the HP (Hodrick-Prescott) filter method (The output gaps obtained from these two sets of data are recorded respectively as *y_nipa* and *y_va*). The above raw data have been used in Chinese and international literature. They have both similarities and certain differentiations, the choice of them needs clear basis. On the premise that the given raw data are reliable, this paper takes the dual stickiness model as an example and experiments with each set of data. Finally, a comprehensive judgment will be made on the use of the six groups of data from such technical perspective as the standard deviation size (*Var_e*) of the interval between the sequence of inflation forecast and the sequence of actual inflation sequence of the model, model goodness of fit (R^2), and the width of the confidence intervals for the estimated parameters. The results of estimation and fitting of this representative model are shown in the Appendix.

Based on the comparative analysis in the appendix, the finally selected original data are: GDP Deflator (*GDP_def*), the logarithmic real *GDP* calculated with the production method that is needed for calculating the real marginal cost gap, and the labor income share (*s*) that is always included in VAR. In the representative model, the corresponding indicators based on other identical conditions cannot show the advantages and disadvantages of QD and HP here through comparison, so the results of the estimation and fitting of the four models under the two different output gaps are all given in Table 1. What needs to be specially mentioned for reference is that Zheng and Wang (2010) studied QD, HP and other technical methods for estimating the output gap in China, and the results show that China's output gap calculated with the HP method is the least reliable, which will be discussed further later.

Table 1 reports the estimation results of the four models of dual stickiness (DS), hybrid New Keynesian (HY), sticky information (MR) and sticky price (NK) under the two different output gaps. According to the research conclusion of Zheng, Wang

(2010), the output gap obtained by the QD method is more reliable than that gained by the HP method, so it is reasonable to choose the QD method as a proxy variable of the real marginal cost gap to perform parameter estimation and model fitting. In view of this, this paper takes the QD method as an example to give a description of the estimation results. First, in general, the heterogeneous prediction models of DS and HY are better fitted than the homogeneous prediction models of MR and NK. Second, the comparison of the two models of NK and MR shows that the former is better than the latter.[5] Since the comparison between DS and HY is relatively complicated, it will be discussed in the next section. Third, in each model, the key point is that the corresponding sticky parameter is significantly different from zero, which means that the corporate sector in the Chinese market has features of both sticky information and sticky price, both of which have corresponding impacts on China's inflation. Fourth, specifically speaking, in the DS model, the estimates of γ and φ indicate that 14%–23% of companies will adjust prices seasonally, with 54%–91% of them using the latest information to determine prices. The exact data are from the point estimation, which shows that the former is 20% (the average frequency of price adjustment is five quarters), while the latter is 65% (the average frequency of updating is 1.5 quarters). It also indicates that in each quarter 13% companies (the average frequency is 7.7 quarters) will make full use of information for optimal pricing (the confidence interval is 0.09–0.18). In the MR model, information stickiness nearly doubles compared with that in the DS model, with only 11% companies updating information (the frequency of information updating being nine quarters on average). It should also be noted that *Var_e* and R^2 indicate that this model fits the worst. Of the three models (DS, HY, NK) that include price stickiness parameters, point estimate and interval estimate are very close, consistently showing that about 20% companies adjust the price every quarter (the ranges of confidence intervals are also close). In HY model, in accordance with the rule of thumb, the proportion of backward-looking companies is about 28%, so the proportion of forward-looking companies is 72%.[6] Xu, Fan and Xue (2015) estimated that the backward-looking behavior takes up 80%, which is very different from the result of this paper, for what they estimated was the backward-looking behavior of the public, instead of the companies. For the ~~corporate~~ sector, the for-profit organization with relatively complete departments and functions, the ratio of adaptive expectations to rational expectations being close to 3:7 is considered to be normal. The estimation results of the HP model can be understood by the same logic. Although research conclusions of Zheng and Wang (2010) worth being referred to, the estimated values under HP models are still given before more similar conclusions are found in related literature. It should also be noticed that the advantages and disadvantages in fitting of the four models have ~~d~~ not changed due to the use of HP or QD. According to the comparative analysis in the appendix, such indicators as R^2 and *Var_e* of the HP type have better performance when the output gap is used as the proxy variable for real marginal cost gap, which is consistently verified in the four models. Here are the forecast inflation sequences and actual inflation sequences for the four models of the HP type (Fig. 1–Fig. 4).

Table 1 Parameter estimation and fitting results of the four models

Note: (1) In the sample period, the first step of VAR (3) includes variables, lagging basis, VAR estimation period and confidence interval, as shown in Note (1) of Appendix; "**" indicates significance at the level of 0.05, "*" indicates significance at the level of 0.10. (2) DS refers to the dual stickiness model; HY stands for the hybrid New Keynesian model; MR stands for the sticky information model; and NK is the sticky price model. MR and NK are special cases of DS; the former is because that $\gamma = 0$ in DS model, while the latter is because that $\varphi = 0$. The meanings of γ, φ, R^2, *Var_e*, *QD*, and *HP* are the same as in Note (2) of the Appendix. Parameter ω refers to the proportion of the current backward-looking company in all companies in the HY model. Parameters ρ, ζ_1 *and* ζ_2 are recombination coefficients, and it will not generate ambiguity to put them in the table. Therefore, the superscript *D* representing the coefficient of the dual stickiness model, and the superscript H representing the coefficient of the hybrid New Keynesian model in the second section of the body part are omitted, for they are lengthy and the deep parameters are not the focus of this paper. They are not listed here as well as in the text, for which see Dupor et al. (2010).

Fig. 1 Inflation forecast sequence of the dual stickness model Fig. 2 Inflation forecast sequence of the hybrid New Keynesian (HY) model

Fig. 3 Inflation forecast sequence of the sticky price (NK) model Fig. 4 Inflation forecast sequence of the sticky information (MR) model

The robustness tests conducted by Dupor et al. (2010) include the following steps. The first step is to change the technical way of obtaining the estimated output gap in the VAR. The benchmark is the quadratic detrending (QD), with its alterative being HP filter.⑦ Then, the labor income share is replaced by the output gap as the proxy variable of real marginal cost gap in the estimation of the second step; and the estimation of the output gap is conducted via QD or HP respectively. Thirdly, the time span of the sample data they used is long enough, so the timeline is divided into two parts, and the output gap is calculated in the VAR through QD or HP. Finally, the strategic complementarity of corporate pricing is considered. In the empirical studies about the above models with US data, the robustness test was passed. As can be seen from Table 1, for China's data, changes in estimation methods for the output gap and in proxy variables for the real marginal cost gap will to some degree influence the parameter estimation results. Since the time series of Chinese data are not long, the data have been adjusted and modified several times, and their performance is relatively poor, the output gap obtained by QD, HP or other means is hardly identical with the unobservable actual output gap. Therefore, this degree of deviation in parameter estimates are still acceptable. However, given the big difference, relative research should be conducted as reference to which type of parameters should be chosen. The basis for the simulation based on the estimated stickiness parameter values in the following section is still the research by Zheng and Wang (2010), and the QD type is chosen. In addition, strategic complementarity is again considered.

Compared with the situation of $\lambda = 1$ ⑧ when there is neither strategic complementarity nor strategic substitution (the benchmark assumption in above), when $\lambda < 1$, the sensitivity of the price to the true marginal cost will reduce. So, the closer λ is to zero, the stronger the real rigidity is; and the closer λ is to one, the stronger the sensitivity is. In other words, λ measures the degree of real rigidity. Different from the situation of $\lambda = 0.2$ in the US research, here it is set that $a = 0.5$ according to Xu, Fan and Xue (2015); with reference to Zhang (2008), the substitution elasticity between different commodities is $v = 1.5$, which is 0.4 after calculation, and the results of parameter estimation also demonstrate changes in a similar degree. Although the parameter estimation results distinguish from each other greatly with different alternatives, the corresponding parameters of concern are generally significantly different from zero. It is still reliable to conclude that the dual stickiness is presented in Chinese data.

4 Dual stickiness model or hybrid New Keynesian model

Based on the two indicators of R^2 and *Var_e*, the dual stickiness model and hybrid New Keynesian model are quite comparable in terms of their functions; to some extent this can be deemed as the extension of the theoretical judgment of Mankiw and Reis (2002). So, can the two models be used indiscriminately? As mentioned earlier, the dual stickiness model is characterized with lagged expectation term that the hybrid New Keynesian model does not have. As long as ζ_2 is significantly different from zero, the former can be distinguished from the latter. In table 1, the point estimates of ζ_2 are respectively 0.08 and 0.05 in the cases of QD and HP. What is more reliable is that the interval estimate for the QD type does not contain zero. Thus, we can come to the conclusion that the dual stickiness model is different from the hybrid New Keynesian model based on Chinese data. After the same supply equation and impact rules are set, this paper will first study whether there is a significant difference in the impulse responses diverging from the equilibrium path under the two supply equations. Then it will examine the data tends to match which nested model of the dual stickiness model and hybrid New Keynesian model.

4.1 Impulse responses

This paper discusses three types of impulses. On the basis of the ~~cost-plus impact~~ proposed by Dupor et al. (2010), the simulation of monetary policy ~~impacts~~ and natural rate ~~impacts~~ is added.

In the standard New Keynesian model, the inter-temporal consumption Euler equation obtained from the optimization of the household sector can be used to obtain the aggregate demand curve under the general equilibrium condition, that is, the IS equation (below is the logarithmic form):

, where y_t represents the output gap; i_t is the nominal interest rate, and $E_t\pi_{t+1}$ refers to expectation for the next inflation. Although the academia has no agreement upon yet

whether the authority in China should adopt some kind of monetary policy, or which kind of monetary policy should they adopt, the authors believe that the direction of China's development is towards the market rules. Therefore, it is assumed that the Taylor Rule in a cashless economy hold here (Woodford, 2003):

Each letter represents the same thing as above; z_t is exogenous, $\psi_\pi > 1$, and ψ_y is non-negative. With the equation established, whether it will produce a unique and stable equilibrium should be considered. Blanchard and Kahn (1980) proposed a test method, usually called the BK condition. At present, if the "check" command is input in the Dynare program, the system will automatically detect whether the requirements are met. To eliminate its uncertainty, this paper sets the initial value of price level in the initial condition, just as Mankiw and Reis (2006) did according to Chapter 2 of Woodford (2003).

The ~~cost-plus impact~~ is due to the theory of changeable ~~cost-plus~~ and the latter relates to real rigidity. Usually a varying commodity elasticity of substitution is assumed, and thus the ideal price markup is also changeable. After operations, a ~~cost-driven~~ inflation equation can be obtained; that is, the ~~impact~~ item v_t is added at the end of the original equation, which is defined as: $\upsilon_t \equiv \kappa(y_t^e - y_t^n) \neq 0$. Here, y_t^e stands for the effective equilibrium output level under the flexible price level and fixed addition, y_t^n is the equilibrium output level with flexible price and time-varying addition, and κ is a structure parameter.

The "natural rate" is defined by Phelps (1968) as the equilibrium unemployment rate (or wage increase) when the actual value of price increase is equal to the expected value, and Phelps (1968) and Friedman (1968) first proposed this concept. Corresponding to the natural unemployment rate is the potential output level. The inference is that the potential output level has nothing to do with the price, so in the long-run, the Phillips curve, that is, the aggregate supply curve, is vertical. Reis (2003) discussed the uncertainty of natural rate and assumed that the natural unemployment rate u_t follows the AR (1) process.

A further assumption is that the three types of impulses obey the rule of AR (1): $x_t = \rho_x x_{t-1} + A^x_t$. In this equation, x_t includes z_t, u_t, v_t; $\rho_x \in (0,1)$; Λ_t^x is a white noise process with zero-mean and covariance.

The following are the numerical simulations for the dynamic paths of the three variables of the total price level, the inflation, and the output gap under the above three types of ~~impacts~~ (each with 1% deviation from equilibrium). Calibration of parameter will be performed first.

, where $\beta = 1$ is out of the consideration of simplifying the inflation equation under the above heterogeneous model; the intertemporal substitution elasticity $\sigma = 1$ is consistent with logarithmic utility function in form; ψ_y and ψ_π are based on Taylor (1993); when ρ_x equals 0.9, it represents a ~~continuous impact~~, while when it is zero, it

refers to the instantaneous ~~impact~~; the three parameters γ, φ, and ω are derived from the parameter estimation of the QD type in Table 2 (based on the literature mentioned above, they are considered to be relatively reliable). What should be noted is that the structure parameters ρ and ζ are the functions of their respective related stickiness coefficients. The impulse responses are shown in figures 5–7.

Table 2 Parameter calibration

These three figures respectively display the impulse responses of inflation (π_t), logarithmic total price (p_t) and logarithmic output gap (y_t) under the sustained (left) and instantaneous (right) monetary policy ~~impacts~~ (Fig. 5), the ~~cost-plus impacts~~ (Fig. 6) and the natural rate ~~impacts~~ (Fig. 7). It is evident that under ~~continuous impacts~~, the dynamic paths of the variables are very similar to those in the dual stickiness model and the New Keynesian model. Under the ~~continuous impact~~ of monetary policy (with increasing interest rates), the total price gradually declines, and the deflationary path follows an inverted hump-shaped pattern. Then, the economy gradually warms up after the first depression. With the sustained ~~cost-plus impacts~~ (price markup), the total price level continues to rise, and the inflation path presents an inverted hump-shaped pattern, which gradually rises to the apex and then slowly declines, forming a mirror-image relation with the output. Due to the ~~lasting impact~~ of the natural rate (an increasing natural unemployment rate), the total price level rises, forming an inflation path similar to that in Figure 6 but the output level drops. When the instantaneous ~~impact~~ occurs, there are significant differences in the dynamic paths of the variables under the two models. The main difference is that the impulse response of inflation and output shows stronger persistence in the ~~mixed~~ New Keynesian model; in addition, the path of the total price is also different.

Fig. 5 Impulse responses of variables under sustained (left) and instantaneous (right) monetary policy ~~impacts~~ Fig. 6 Impulse responses of variables under sustained (left) and instantaneous (right) ~~cost-plus impacts~~

Fig. 7 Impulse responses of variables under sustained (left) and instantaneous (right) ~~impacts~~ of natural rate

By simulating the dynamic paths of inflation, the total price and the output gap under ~~impacts~~, we clearly see that the impulse responses of the macroscopic variables are significantly different under the instantaneous ~~impacts~~ in the models, although the impulse responses under ~~continuous impact~~ are quite consistent.

4.2 Data Matching

According to the estimation of the key parameter ζ_2 to the impulse responses with significant differences in the two supply equations, we have concluded that the dual stickiness model and the New Keynesian model have the similar goodness of fit. Naturally, we will ask which supply equation is more in line with China's national

conditions in the analysis of issues such as the optimal monetary policy. This chapter tries to answer this question. With reference to the practice of Dupor et al. (2010), the dual stickiness model and the hybrid New Keynesian model are nested into one (coefficient plus the superscript *G*); specifically, ω percent of backward-looking companies are added into the dual stickiness model. Thus, the price for each quarter is adjusted as:

The following inflation equations can also be deduced:

The meanings of the letters in the above two equations are consistent with those in the foregoing equations. It is easily observed that, in the nested model, there are additional inflation items of two-period lag compared with the dual stickiness Model. The parameter estimation and model fitting results are as follows.

Table 3 shows the parameter estimation and fitting results under the above inflation equations. The comparison of the related values listed in Table 1 and the point estimation values of the three structure parameters of γ, φ and ω show that the hybrid New Keynesian model fit the Chinese data better than the dual stickiness model (Dupor et al., 2010).

Table 3 Estimation and fitting of the nested model of the dual stickiness model and the hybrid New Keynesian model

Estimates of structure parameters and results of model fitting; Estimates of coefficients

What are the underlying reasons? The essential difference between the two models is that the dual stickiness model has an additional lagged expectation term compared with the hybrid New Keynesian model. Moreover, although both contain lagged inflation, the former is endogenous with rational expectations, while the latter is exogenous with adaptive expectations. In other words, although both are nested in different expectation forms, only the hybrid New Keynesian model contains non-rational expectations. As is pointed out by Mankiw and Reis (2002), the difference between rational expectations and non-rational expectations will contribute to different results of the event of disclosing policy information beforehand and in time. On the other hand, the US market is relatively complete with higher policy transparency, and its corporate entities are relatively mature in that background. However, China's social market economy changes each day, and all levels in the ~~corporate~~ sector are still taking shape in China (Xu et al., 2015). The rich, big, information-oriented companies have a fine basis of rational expectations, but many small and medium-sized enterprises simply pursue the non-rational expectation of adaptability. The policy transparency should be improved in China. All these factors have led to Chinese data's preference for the hybrid New Keynesian model.

5 Summary

This paper reviews the homogeneous sticky information and sticky price expectation models under the theory of price rigidity, and the heterogeneous dual stickiness and hybrid New Keynesian expectation models. With China's macro data carefully studied and rigorously processed by Chang et al. (2015), this paper estimates the sticky characteristics of the ~~corporate~~ sector in Chinese market by following the method in Dupor et al. (2010). There are two moderate conclusions: the heterogeneous expectation models of DS and HY fit better than the MR and NK, and MR fits the worst; second, the ~~corporate~~ sector in the Chinese market sectors has the characteristics of both sticky information and sticky price, both of which have a corresponding impact on China's inflation. We have also estimated that under the dual stickiness model, the average time span for companies adjusting prices is five quarters, and the average frequency of optimizing prices based on the latest information is 7.7 quarters. In the hybrid New Keynesian model, the proportion of forward-looking rational expectations of companies is estimated to be 72%, and that for backward-looking adaptive expectations is 28%. Finally, a significant conclusion is that although it is hard to tell whether the dual stickiness model or the hybrid New Keynesian model fits better, it is found that the analysis of impulsive responses and the comparison of parameter estimates in the nested models and the two original models show that China's data tend to match the latter and China should choose to the hybrid New Keynesian model for analyzing domestic issues such as optimal monetary policy.

Appendix: Screening of data

Since there are multiple columns of raw data available, and the data processing methods for obtaining the variables needed are also diverse, it is not easy to find a method of which the merits and demerits can be distinguished easily. The screening of data series should involve the comparison of the parameter estimates and fitting differences between the four models under China data.. It is also a tedious and unnecessary task to compare all the candidate data sets and various processing methods in turn in the four models. Therefore, it is a relatively good method by selecting representative models, comparing the candidate data sets and the estimated results of the processing methods, and applying them to the four models uniformly. The DS model is chosen because it is the most inclusive one of the four models: the MR model and the NK model are only special cases of it; there is only one additional lagged expectation item (coefficient $\zeta 2$) compared with the HY model.

The comparison and screening of the original data set and data processing methods are as follows. The first is to observe the lines. The main difference between line 2 and line 3 is whether *y_nipa* or *y_va* is used in VAR. The indicators *Var_e* and R^2 both show that the latter is better than the former when the *p*-value is equivalent. This preliminary conclusion can be further confirmed by comparing the aforementioned indicators in line 7 and line 8. After *y_va* is selected, it is easily found from the above indicators in lines 3 and 4 as well as lines 8 and 9 that CPI is better than RPI. With a comparison between lines 3 and 5, as well as lines 8 and 10, the above indicators

show that *GDP_def* performs better than *CPI*. Then, the comparison between lines 5 and 6, as well as lines 10 and 11 indicates that both QD and HP have relatively good performance. Next is to observe block by block. The authors have divided the above table into the upper and lower areas according to the estimation results. The obvious difference is that the labor income share and the output gap are respectively used as the proxy variables of the real marginal cost gap, and the stickiness coefficients are obtained by point estimation. In various other corresponding combinations, the latter is always more than double of the former. Further observations show that, under the same confidence level, the confidence intervals of the estimated parameters in the lower part of the second column are significantly narrower than those in the upper half, and the confidence intervals of the upper and lower parts of the third column are not significantly different. From these perspectives, the output gap is better than the labor income share as the aforementioned proxy variable.

Attached table: Parameter estimation and fitting results of the representative DS model

Notes: (1) The sample span is from the first quarter of 1996 to the second quarter of 2014. Since the time series of sample data available in China are not long enough, the confidence interval with a confidence of 0.95 is relatively wide, the confidence interval should be narrowed appropriately for a more reliable estimation. As it is impossible to collect longer sequence of data, this paper chooses to double the level of significance, that is., the brackets "[]" represent a confidence interval with a confidence of 0.9. In the parentheses "()," the brackets are preceded by *p*-values. In the first step, VAR (3) includes three variables: inflation rate, labor income share, and output gap. The three-order lag is based on the Bayesian information criterion; the initial time of VAR estimation is extended by 0.25 (k-1) time periods, with k = 12 (Dupor et al., 2010), so the VAR sample period is from the second quarter of 1993 to the second quarter of 2014.(2) The field before the semicolon in the first column indicates that the third variable is the output gap (*y_nipa* or *y_va*) of the first step (VAR) of the estimation process, the other two being the inflation rate and the labor income share (*s*). The different price indices for calculating inflation include the consumer price index (*CPI*), the retail price index (*RPI*), and the GDP deflator (*GDP_def*). Other factors include the labor income share (*s*) as the proxy variable of the real marginal cost gap, and the output variable (*y_va*) also as the proxy variable based on the GDP calculated through the quadratic detrending (QD) or HP filter in the expenditure method, or the output gap (*y_va*) based on the GDP calculated in the production method. The field after the semicolon in the first column indicates that the labor income share and the output gap are used as proxy variables for the actual marginal cost gap in the estimation of the second step. The second column reports the proportion of companies that do not adjust prices in each period, that is, the degree of price stickiness (γ). The third column reports the proportion of companies without updated information in each period of price adjustment, that is, the degree of information stickiness (φ). The fourth column reports the standard deviation (*Var_e*)

of the interval between of the model inflation forecast sequence and the actual inflation sequence.

(1) Peng, X. *Economic Research Journal* (经济研究), (12) (2011).

(2) Wang, L., Zhang, L. & Liu, W. *Economic Research Journal* (经济研究), (10) (2012).

(3) Wang, J. *Management World* (管理世界), (8) (2009).

(4) Xu, Z., Fan, H. & Xue, H. *China Economic Quarterly* (经济学(季刊)), (4) (2015).

(5) Zhang, W. *Economic Research Journal* (经济研究), (3) (2008).

(6) Zheng, T. & Wang, X. *Economic Research Journal* (经济研究), (10) (2010).

(7) Ball, L., 1994, "Credible Disinflation with Staggered Price Setting", *American Economic Review*, Vol. 84 No. 1, pp. 282–89.

(8) Blanchard, O. J. and C. M., Kahn, 1980, "The Solution of Linear Difference Models Under Rational Expectations, Econometrica", *Journal of the Econometric Society*, pp. 1305–1311.

(9) Blanchard, O. J. and N. Kiyotaki, 1987, "Monopolistic Competition and the Effects of Aggregate Demand", *The American Economic Review*, pp. 647–666.

(10) Branch, W. A. and B. Mc Gough, 2009, "A New Keynesian Model with Heterogeneous Expectations", *Journal of Economic Dynamics and Control*, Vol. 33 No. 5, pp. 1036–1051.

(11) Calvo, G. A., 1983, "Staggered Prices in a Utility-Maximizing Framework", *Journal of Monetary Economics*, Vol. 12 No. 3, pp. 383–398.

(12) Chang, C., K. Chen, D. F. Waggoner and T. Zha, 2015, "Trends and Cycles in China's Macroeconomy", *National Bureau of Economic Research*, No. w21244.

(13) Christiano, L. J., M. Eichenbaum and C. L. Evans, 2005, "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy", *Journal of Political Economy*, Vol. 113 No. 1, pp. 1–45.

(14) Clarida, R., J. Gali and M. Gertler, 1999, "The Science of Monetary Policy: A New Keynesian Perspective", *National Bureau of Economic Research*, No. w7147.

(15) Dupor, B., T. Kitamura and T. Tsuruga, 2010, "Integrating Sticky Prices and Sticky Information", *The Review of Economics and Statistics*, Vol. 92 No. 3, pp. 657–669.

(16) Fischer, S., 1977, “Long-Term Contracts, Rational Expectations and the Optimal Money Supply Rule”, *Journal of Political Economy*, Vol. 85 No. 1, pp. 191–205.

(17) Fuhrer, J. and G. Moore, 1995, “Inflation Persistence”, *Quarterly Journal of Economics*, Vol. 110, No. 1, pp. 127–159.

(18) Friedman, M., 1968, “The Role of Monetary Policy”, *American Economic Review*, Vol. 58, pp. 1–17.

(19) Galí J. and M. Gertler, 1999, “Inflation Dynamics: A Structural Econometric Analysis”, *Journal of monetary Economics*, Vol. 44 No. 2, pp. 195–222.

(20) Galí J., M. Gertler and J. D. Lopez-Salido, 2001, “European Inflation Dynamics”, *European Economic Review*, Vol. 45, pp. 1237–1270.

(21) Galí J., M. Gertler and J. D. Lopez-Salido, 2005, “Robustness of the Estimates of the Hybrid New Keynesian Phillips Curve”, *Journal of Monetary Economics*, Vol. 52 No. 6, pp. 1107–1118.

(22) Lucas, R. E., Jr., 1972, “Econometric Testing of the Natural Rate Hypothesis”, in O. Eckstein, ed., *The Econometrics of Price Determination*, Board of Governors of the Federal Reserve System.

(23) Mankiw, N. G., 2001, “The Inexorable and Mysterious Tradeoff between Inflation and Unemployment”, *The Economic Journal*, Vol. 111, pp. 45–61.

(24) Mankiw, N. G. and R. Reis, 2002, “Sticky Information Versus Sticky Prices: A Proposal to Replace the New Keynesian Phillips Curve”, *Quarterly Journal of Economics*, Vol. 117, No. 4, pp. 1295–1328.

(25) Mankiw, N. G. and R. Reis, 2006, “Pervasive Stickiness”, *American Economic Review*, Vol. 96 No. 2, pp. 164–169.

(26) Mankiw, N. G. and R. Reis, 2007, “Sticky Information in General Equilibrium”, *Journal of the European Economic Association*, Vol. 2, pp. 603–613.

(27) Mccallum, B. T., 1997, “An Optimization-Based Econometric Framework for the Evaluation of Monetary Policy: Comment”, *National Bureau of Economic Research, Macroeconomics Annual*, Vol. 12, pp. 355–359.

(28) Mc Callum, B., 1998, “Stickiness: A Comment”, *Carnegie-Rochester Conference Series on Public Policy*, Vol. 49, pp. 357–363.

(29) Meyer-Gohde, A., 2010, “Linear Rational-Expectations Models with Lagged Expectations: A Synthetic Method”, *Journal of Economic Dynamics& Control*, Vol. 34 No. 5, pp. 984–1002.

(30) Phelps, E., 1968, “Money-Wage Dynamics and Labor Market Equilibrium”, *Journal of Political Economy*, Vol. 76, pp. 678–711.

(31) Reis, R., 2003, “Where is the Natural Rate? Rational Policy Mistakes and Persistent Deviations of Inflation from Target”, *Advances in Macroeconomics*, Vol. 3 No. 1, pp. 1–38.

(32) Reis, R., 2006a, “Inattentive Consumers”, *Journal of Monetary Economics*, Vol. 53 No. 8, pp. 1761–1800.

(33) Reis, R., 2006b, “Inattentive Producers”, *Review of Economic Studies*, Vol. 73 No. 3, pp. 793–821.

(34) Reis, R., 2009, “A Sticky-Information General-Equilibrium Model for Policy Analysis”, *Monetary Policy under Uncertainty and Learning*, pp. 227–284.

(35) Rotemberg, J. J. and M. Woodford, 1997, “An Optimization-Based Econometric Framework for the Evaluation of Monetary Policy”, *National Bureau of Economic Research, Macroeconomics Annual*, Vol. 12 No. 12, pp. 297–361.

(36) Rotemberg, J. J., 1982, “Monopolistic Price Adjustment and Aggregate Output”, *Review of Economic Studies*, Vol. 49 No. 4, pp. 517–531.

(37) Taylor, J. B., 1980, “Aggregate Dynamics and Staggered Contracts”, *Journal of Political Economy*, Vol. 88 No. 1, pp. 1–23.

(38) Taylor, J. B., 1993, “Discretion Versus Policy Rules in Practice”, *Carnegie-Rochester Conference Series on Public Policy*, Vol. 39, pp. 195–214.

(39) Trabandt, M., 2009, “Sticky Information vs. Sticky Prices: A Horse Race in a DSGE Framework”, Sveriges Riksbank Working Paper No. 209.

(40) Walsh, C. E., 2003, *Monetary Theory and Policy*, MIT Press, 2nd edition.

(41) Woodford, M., 2003, *Interest and Prices: Foundations of a Theory of Monetary Policy*, Princeton University Press.

Using the Chinese macro data that have been studied and processed by Chang et al. (2015) and following the method used by Dupor et al.(2010), we estimate the degree of stickiness and analyze the sticky characteristic of the corporate sector in China. The findings are as follows: (1) Both sticky information and sticky price are present in Chinese data; (2) dual stickiness models can be distinguished from hybrid New Keynesian models; (3) under the dual stickiness model, the firm adjust prices every five quarters and use the latest information to determine prices every 7.7 quarters on average, and under the hybrid models, 72 percent of the firms are forward-looking while 28 percent are backward-looking; and (4) the data prefers the hybrid New

Keynesian model over the dual stickiness model although the models' goodness of fit are almost the same, which imply that we should still use the hybrid New Keynesian model when we study the monetary policy in China.

The author, Deng Yanfei, thanks the China Scholarship Council and the graduate school of East China Normal University for their financial support. The author appreciates the warm help from two constructors of the dual stickiness model, Bill Tupor, professor of Ohio State University, and Tomiyuki Kitamura, associate professor of Kyoto University, and is also grateful to suggestions from Associate Professor Huang Haifang of the University of Alberta and from the scholars at the China Youth Economist Forum and the forum held by Huozhi 365, an ecomomic research institute.

① The other three are respectively: basic characteristics in line with the DSGE framework, monopolistic competition, and short-term non-neutrality of monetary policy.

② There is also salary rigidity. Price rigidity and salary rigidity have the same mechanism in the traditional sticky price theory, but their sources are different. In addition, Mankiw and Reis (2006), the founders of the sticky information theory, proposed that information stickiness, which causes that prices and wages cannot be adjusted in time, commonly exist. These studies focus on nominal rigidity.

③ See Blanchard and Kiyotaki (1987) for the microscopic basis of the equation. The equation implies the mechanism of pro-cyclical inflation, namely that during the period of economic expansion, output demand rises, supply increases, the marginal cost of companies goes up, and the price of monopolistic competitive companies surges. However, whether inflation is pro-cyclical depends on the proportion of the companies adjusting their prices.

④ The original code was provided by Associate Professor Tomiyuki Kitamura, one of the builders of the dual stickiness model, and the authors adjusted it slightly according to actual needs.

⑤ With the addition of the MR model to the NK model, the variance of the gap between the theoretical inflation and the actual inflation decreased by 15.57%; when the NK model is added to the MR model, the variance decreased by 36.81%. This explains from another perspective that with China's data, the sticky price model works better, consistent with the conclusion based on the US data.

⑥ According to Footnote 13 of Dupor et al. (2010), Gal íand Gertler (1999) and Gal í et al. (2005) emphasized that the key parameters for assessing the relative importance of forward-looking and backward-looking behaviors are γ_f and γ_b, which are functions of γ and ω. When discount factor is 1, $\gamma f = \gamma/(\gamma + \omega)$,$\gamma b = \omega/(\gamma + \omega)$

⑦ In this regard, the authors have something more for the discussion. Both technical methods can obtain the estimate of the output gap, but there is only one real output gap. If the model is correct, the obtained output gap estimate should be close to the potentially unobservable one, and then the parameter estimate is more accurate. If the output gaps obtained by these two methods are not consistent with the real output gap, but they are very close to each other, they are not necessarily accurate (in consistence with the objective), although the parameter estimate does not change much, that is, the result is robust. Therefore, the robustness test in this step is just one of the reference options. It is precisely because of this that Table 2 has previously listed the estimation results with certain differences of both models. As for which one to choose, although the study has referred to the research by Zheng Tingguo and other scholars, both conditions are still listed here.

⑧ According to Dupor et al. (2010), Gal íet al. (2001) and Walsh (2003) discussed a production function with a diminishing labor income, $Y_{it} = N_{it}^{\alpha}$, where $\alpha < 1$. In this case, the optimal pricing equation with complete information of companies has an additional coefficient, λ, in front of the marginal cost compared with the former forward-looking optimal pricing equation. In $\lambda = \alpha/[1 + (1 - \alpha)(v - 1)]$, v is the alternative elasticity between different products.

⑨ It is stated on page 129 in Mankiw and Reis (2002 that to some extent, the dynamic response of the sticky information model is similar to the Phillips curve with backward-looking adaptive expectations. It is also pointed out that the former with rational expectations and the latter with irrational expectations will produce very different results in terms of disclosing policy information beforehand and in time.