

Testing an Alternative Price-Setting Behavior in the New Keynesian Phillips Curve: Extrapolative Price-Setting Mechanism*

Yoonseok Choi**
Suffolk University

Sunghyun Henry Kim***
Sungkyunkwan University and Suffolk University

Abstract

The hybrid New Keynesian Phillips curve (NKPC) has been widely used in monetary policy literature (e.g. Gali and Gertler, 1999) as it contains both forward-looking and backward-looking components and therefore fits the data well. A typical backward-looking part of price setting behavior assumes that firms use the previous period's price. In this paper, we propose a generalized version of the hybrid NKPC by incorporating the extrapolative price-setting mechanism in the backward-looking part of the price setting behavior. We assume that when firms set the price at period t , they use information on price in period $t-1$ plus a portion of the change in prices between $t-1$ to $t-2$, which permits the trend in past price changes (partial error correction). Under this generalized setting, we derive reduced and structural NKPC explicitly. It turns out that the newly derived NKPC is a nesting model of the original hybrid NKPC in Gali and Gertler (1999). The empirical results show that the extrapolative component is strongly significant in explaining the inflation dynamics. In addition, the generalized version of the hybrid NKPC fits the data better than the original hybrid NKPC in terms of various measures for empirical performance such as AIC, BIC, root mean squared error and mean absolute error.

JEL classification: E31, E52

Keywords: extrapolative price-setting, inflation dynamics, New Keynesian Phillips Curve, forward-looking, backward-looking.

* This work is supported by the Korea Research Foundation Grant funded by the Korean Government (NRF-2013S1A5A2A03044693).

** Department of Economics, Suffolk University, Boston, USA. E-mail: ychoi2@suffolk.edu.

*** Corresponding Author. Department of Economics, Sungkyunkwan University, Seoul, Korea and Department of Economics, Suffolk University, Boston, MA, USA. Tel: 02-760-0421, E-mail: shenrykim@skku.edu.

1. Introduction

The New Keynesian Phillips Curve (NKPC) has been widely used in monetary policy literature because it captures forward-looking behavior of rational agents. However, the purely forward-looking NKPC performs poorly in empirical test as it fails to capture inflation persistence observed in the data.¹ This empirical failure led economists to expand the standard NKPC by including a backward-looking price setting behavior as well as forward-looking part (Gali and Gertler 1999). Concerning empirical performance, many studies have shown that this hybrid NKPC model, by emphasizing the role of lagged inflation to explain the intrinsic persistence of inflation, fits the data better than the purely forward-looking NKPC (e.g. Fuhrer and Moore 1995; Fuhrer 1997; Roberts 1997 and 2005; Gali et al. 2001; Christiano et al. 2005).

However, many hybrid NKPC models are based on ad-hoc inclusion of lags of inflation and use a reduced-form equation for estimation without any structural model (e.g. Fuhrer 1997; Roberts 2005). Exceptions are, for example, Gali and Gertler (1999), Smets and Wouters (2003) and Sbordone (2006) who derive both structural and reduced-form equations based on hybrid NKPC models and therefore all structural parameters can be recovered and identified from the reduced-form equation.² The backward looking part in most previous papers assume that firms use a simple rule of thumb that depends on price information at time $t-1$ only, which forces the model to have only one lag of inflation. Roberts (2005) points out, however, that there is no logical reason why only a single lag of inflation should be included for the backward-looking behavior because a single lag may not be enough to offer a good empirical description for inflation behavior.³ In reality, it is reasonable to think that firms use more sophisticated price setting rules than a simple rule of thumb.

This paper attempts to improve in these two aspects: an arbitrary model specification (ad hoc inclusion of lags of inflation) and the need for more sophisticated backward-looking pricing behavior. In particular, we assume that firms use price information in the two previous periods (extrapolative price-

¹ An unsatisfactory empirical result that the standard NKPC produces is the “disinflationary boom” argued by Ball (1994). In a completely forward-looking model, inflation can jump as a response to a shock to output and the model does not exhibit the intrinsic persistence of inflation. As Fuhrer and Moore (1995) and Fuhrer (1997) argue, the standard NKPC seems to fail to provide enough inertia in inflation and does not fit the post-war U.S. data well.

² Gali and Gertler (1999) assume that there are two types of firms that set their prices (forward-looking firms and backward-looking firms with a simple rule-of-thumb price setting rule). Smets and Wouters (2003) and Sbordone (2006) use the partial indexation assumption and derive the hybrid NKPC which contains one forward and one lagged inflations.

³ Roberts (2005) introduces a general class of backward-looking component which is a lag polynomial of inflation similar to the accelerationist Phillips curve. He uses a simple four-quarter moving average of inflations for backward-looking behavior for the reduced-form equation. In addition to Roberts (2005), other researchers attempt to add additional lags of inflation. For example, see Fuhrer and Moore (1995), Fuhrer (1997), Kozicki and Tinsley (2002).

setting mechanism) and solve the structural model based on this extrapolative price setting behavior. As a result, we have two lags of inflation in the reduced-form NKPC and an additional structural parameter in the structural NKPC. We name this model as a generalized hybrid NKPC model (compared to hybrid NKPC à la Gali and Gertler, 1999). We first test whether the newly proposed price-setting rule presents a reasonable empirical validity using various test statistics and then test if the generalized hybrid NKPC performs better than the hybrid NKPC in various evaluation criteria for model fit.

Compared to “static or naïve” expectations formation adopted in Gali and Gertler (1999), the idea of the extrapolative price-setting mechanism is based on the extrapolative expectations formation. It states that the price-setting behavior at time t is a function of price at time $t-1$ and the error component between prices in $t-1$ and $t-2$, a partial correction added to permit the trend.⁴

We show that the generalized hybrid NKPC is a nesting specification of the hybrid NKPC. We test for a zero restriction on the coefficients in the reduced-form and structural generalized hybrid NKPC. The Wald statistic rejects the null hypothesis of zero restriction on estimated parameters, implying that the newly proposed NKPC is a reasonable model specification for inflation dynamics in the statistical sense. Baseline estimation results show that the forward-looking component still plays an important role in explaining current inflation and the slope coefficient of the labor share is positive, which is in line with the earlier findings. We find that the second lag of inflation (extrapolative coefficient or coefficient of the price trend) in the reduced-form (structural) equation is statistically meaningful. In addition, including the second lag of inflation reduces the role of forward-looking part and increases the role of backward-looking component. The estimate of the extrapolative coefficient (trend of change in prices) in the structural equation is highly significant and positive, implying that backward-looking firms tend to take account of the past trend in price changes when they set their prices and the overall behavior of inflation over the whole sample period is fairly stable. To test whether the generalized hybrid NKPC performs better than the hybrid NKPC, we use various measures such as the Akaike information criterion (AIC) and the Bayesian information criterion (BIC), the root mean squared error (RMSE), the mean absolute error (MAE), the mean absolute percentage error (MAPC) and the Theil U statistics. Test statistics suggest that our model is more preferred by the data, implying that the effects of the second lag of inflation and extrapolative coefficient (coefficient of the price trend) on current inflation cannot be disregarded. These overall results are reasonably robust from various sensitivity check. The sub-period analysis shows that the behavior of inflation in the pre-Volcker period is quite different from that in the post-Volcker period, and this result is well explained by the estimated coefficient of the price trend in

⁴ Sometimes, it is called the “trend following” price expectations because it contains the change in recent prices reflecting the direction of price movements.

the model, which is a distinct feature compared to the hybrid NKPC.

This paper is organized as follows. In Section 2, we provide evidence on the extrapolative behavior from various fields in the literature. Section 3 derives the generalized hybrid NKPC. In Section 4, we describe the estimation method, its possible issue and the data. Section 5 presents the estimation results along with sensitivity and sub-period analyses. Section 6 concludes this paper.

2. Literature on Extrapolative Expectations

The particular form of price-setting mechanism assumed in this paper is motivated by the extrapolative expectations formation. Agents are said to have extrapolative beliefs (or show extrapolative behavior) when they place relatively high weights on the most recent past observation. A wide variety of early studies corroborates that many economic agents base their expectations on extrapolative beliefs. The earliest and influential work on the extrapolative expectations formation is Metzler (1941) and Goodwin (1947).⁵ These two studies examine firms' economic behaviors with extrapolative expectations. In particular, Metzler (1941) uses the extrapolative expectations formation to examine dynamic properties of business cycles using an inventory model with sales-output lags. Goodwin (1947) uses a simple cobweb model when producers use the extrapolative expectations formation to predict their future prices to examine dynamics of prices and markets. Johnson and Plott (1989) do experimental research on performance of different types of price expectations models to examine individual and market behaviors in four types of supply-lag auction and posted-price markets. Based on responses of the subjects who participate in the experiments, they show that the sellers' behavior for posted price trading is fairly well explained by the extrapolative expectations formation.

Some studies empirically test if agents employ the extrapolative scheme. Turnovsky (1970) uses the Livingston survey data to test which price expectations formation provides the best description of price movements and inflation dynamics. The results show that the price movements can be well described by the extrapolative scheme. Svendsen (1994) directly employs the firms' survey data in Norway and find that firms base their expectations on the future prices and demand in an extrapolative manner. Reckwerth (1997) uses the survey data on CPI in Germany to examine the relationship between inflation and output and find that the extrapolative coefficient is significant and well describes the inflation movement.

Recent research places an emphasis on the effect of heterogeneous expectations (e.g., interaction

⁵ They formulate the extrapolative expectations explicitly in their papers but they did not name it the extrapolative expectations. Muth (1961) first called this type of expectations formation "extrapolative expectations."

between rational and extrapolative expectations) on inflation dynamics. Pfajfar and Zakelj (2013) use a simple new Keynesian model to examine the effectiveness of monetary policy when there are different types of expectations (rational, adaptive, extrapolative and adaptive learning, etc) in the economy. Using experimental data, they show that a large portion of subjects uses the extrapolation rule which produces a high volatility of inflation and that the interaction between rational and extrapolative expectations play a crucial role in determining the performance of monetary policy.

Another branch of literature actively discusses the importance of extrapolative expectations in the context of exchange rates and asset markets. Some studies use experimental and survey data to examine how agents form expectations on exchange rates movements including rational, static, extrapolative and adaptive expectations based on different horizons of exchange rates (e.g., Frankel and Froot 1987a and 1987b; Cavaglia et al. 1993; Chinn and Frankel 2000). Overall, empirical evidence suggests that the extrapolative mechanism gives a better description on movements of exchange rates than other expectations formation such as rational or static expectations. Several studies on asset markets document that many individuals, even experts, tend to extrapolate the past performance in predicting future returns and show how extrapolative beliefs have effects on market behavior. If the recent past performance exhibits high returns, agents tend to expect future returns to remain at a high level (De Bondt 1993; Sirri and Tufano 1998; Vissing-Jorgensen 2003). Some studies applied extrapolative expectations in explaining the recent housing market bubble and global financial crisis (Gerardi et al. 2008; Barberis 2011). Overall, a number of studies in various fields of Economics demonstrate the importance of extrapolative beliefs on market and economic behaviors.

3. Derivation of the Generalized Hybrid NKPC

In this section, we theoretically formulate the generalized hybrid NKPC that reflects the extrapolative mechanism in price setting behavior. We follow the notations in Galí and Gertler (1999) in most cases so that we can compare our results directly to their results.

The optimal aggregate price level is expressed as a convex combination of the previous price level p_{t-1} and the optimal reset price \bar{p}_t^*

$$(1) \quad p_t = \theta p_{t-1} + (1 - \theta) \bar{p}_t^*,$$

where \bar{p}_t^* is the price selected by firms that are able to change price at time t and $1 - \theta$ is the probability that firms may adjust price during this period. Following Galí and Gertler (1999), we

assume that there are two types of firms when they update their prices. A portion $1 - \omega$ of firms follows “forward-looking price rule,” whereas the other portion ω of firms employs a “backward-looking price rule.” Then, the newly set price index can be expressed as

$$(2) \quad \bar{p}_t^* = (1 - \omega)p_t^F + \omega p_t^B.$$

Forward-looking firms seek to maximize its discounted sum of profits under the sticky price setting as in Calvo (1983). The first-order approximated version (first-order linearization) of the optimally updating pricing rule has the form of

$$(3) \quad p_t^F = (1 - \beta\theta) \sum_{i=0}^{\infty} (\beta\theta)^i E_t \{ mc_{t+i}^n \},$$

where mc_t^n denotes a nominal marginal cost (forcing variable for the supply side), β is a discount factor for firms and θ indicates the probability of sticking to the previous price level.

For the formulation of “backward-looking” price, Gali and Gertler (1999) assume a very simple rule for setting the price $p_t^B = \bar{p}_{t-1}^* + \pi_{t-1}$, which depends only on the most recent period $t-1$ with a correction for inflation for the newly set price in period t . In this paper, however, we consider an alternative price setting scheme for the backward-looking part, an extrapolative price setting mechanism.

The extrapolative price setting scheme (partial error correction mechanism) in period t consists of the price in period $t-1$ plus a portion of the change in prices between $t-1$ to $t-2$, which represents the correction added to permit the trend in past price changes. Hence, the extrapolative price setting mechanism is formulated as

$$(4) \quad p_t^B = (\bar{p}_{t-1}^* + \pi_{t-1}) - \alpha [(\bar{p}_{t-1}^* + \pi_{t-1}) - (\bar{p}_{t-2}^* + \pi_{t-2})],$$

where α is an extrapolative coefficient (coefficient of a partial error correction term or coefficient of the price trend) capturing the trend (or direction) of changes in prices.⁶ In this price setting mechanism, producers take account of both past level of prices and direction of change. The parameter α is theoretically meaningful and admissible when it lies between -1 and 1.

The equation (4) can be rewritten as

$$(5) \quad p_t^B = (1 - \alpha)(\bar{p}_{t-1}^* + \pi_{t-1}) + \alpha(\bar{p}_{t-2}^* + \pi_{t-2}).$$

⁶ Metzler (1941) and Goodwin (1947) called this parameter the “coefficient of expectation.”

which indicates that the extrapolative price setting scheme is a convex combination of the newly reset prices at $t-1$ and $t-2$ with the weight α on $t-2$. Prices in periods $t-1$ and $t-2$ are corrected for inflation in those periods. It is a “generalized” version of the static price setting scheme (simple rule of thumb) in Gali and Gertler (1999).

If the extrapolative coefficient α is equal to zero, equation (5) reduces to the hybrid NKPC in Gali and Gertler (1999). If α is not zero, the interpretation is as follows: (a) when $\alpha < 0$, firms extrapolate the past trend expecting that the trend would continue. In this case, firms tend to set their prices by expecting a rise in prices, which creates a further rise in prices in the future; (b) when $\alpha > 0$, firms expect that the trend in past price would revert. In this case, firms have an inclination to set their prices in anticipation of a fall (rise) in prices following a rise (fall) in prices⁷; (c) when $\alpha = 0$, backward-looking firms do not consider the past trend when they set their prices.

If firms employ the extrapolative price-setting mechanism in (4), a variant of the hybrid NKPC becomes:

$$(6) \quad \pi_t = \eta_f E_t \pi_{t+1} + \eta_{b1} \pi_{t-1} + \eta_{b2} \pi_{t-2} + \varphi m c_t,$$

where

$$\eta_f = \frac{\beta\theta}{\theta}; \quad \eta_{b1} = \frac{\omega[1-2\alpha+\alpha\theta(1-\beta)]}{\theta}; \quad \eta_{b2} = \frac{\alpha\omega}{\theta}; \quad \varphi = \frac{(1-\beta\theta)(1-\theta)(1-\omega)}{\theta};$$

$$\theta = \omega + \theta[1 - \omega + \beta\omega(1 - 2\alpha + \alpha\theta)].$$

The equation (6) shows how the structural parameters are related to the reduced-form parameters. We refer to this newly derived equation as the generalized hybrid NKPC.⁸ If no firms use the backward-looking price setting rule (i.e. $\omega = 0$), this hybrid NKPC reduces to the purely forward-looking NKPC.

For the comparison purpose, the hybrid NKPC in Gali and Gertler (1999) is

$$(7) \quad \pi_t = \gamma_f E_t \pi_{t+1} + \gamma_b \pi_{t-1} + \lambda m c_t,$$

⁷ In some literature, the case of $\alpha < 0$ is called “bandwagon” movement (or *destabilizing movements*), while that of $\alpha > 0$ is called “regressive” movement (or *stabilizing movements*). These terms are widely used in the literature studying the expectations hypothesis for exchange rate. For example, see Frankel and Froot (1987a and 1987b).

⁸ Detailed derivation of this equation is available upon request.

where

$$\gamma_f = \frac{\beta\theta}{\phi}; \gamma_b = \frac{\omega}{\phi}; \lambda = \frac{(1-\beta\theta)(1-\omega)(1-\theta)}{\phi}; \phi = \theta + \omega[1 - \theta(1 - \beta)].$$

We can easily verify that the original hybrid NKPC in (7) is a special case of the generalized hybrid NKPC in (6) when $\alpha = 0$.

An important and distinct feature of our model is that we have new parameters (α and η_{b2}) in both reduced and structural-form NKPC which have economically important interpretations. In addition, the four structural parameters in the model can be fully recovered by estimating the reduced-form equation. In other words, all the parameters in the reduced form equation are functions of structural deep parameters derived from the model. Most previous studies that compare the relative importance of backward- and forward-looking parts have used an ad hoc version of backward-looking part in the model, where they cannot provide any information on structural parameters.

4. Estimation Method and Data

In order to deal with the expectation terms in estimating equations and to avoid the potential endogeneity problem, we use the generalized method of moments (GMM) technique. We use the J-statistic to test the validity of over-identifying restrictions in the estimated model (for instruments exogeneity). Another important issue in IV estimation is weak instruments (for instruments relevance).⁹ For weak instrument tests, we use the Anderson-Rubin (AR) statistic (Anderson and Rubin, 1949).

Based on these test results, we estimate both generalized hybrid NKPC in (6) and typical hybrid NKPC in (7). For GMM estimation, the moment conditions (orthogonality conditions) for two NKPCs are specified as follows:

$$(8) \quad E_t[(\pi_t - \eta_f E_t \pi_{t+1} - \eta_{b1} \pi_{t-1} - \eta_{b2} \pi_{t-2} - \varphi m c_t) z_t] = 0 \text{ (generalized hybrid NKPC),}$$

$$(9) \quad E_t[(\pi_t - \gamma_f E_t \pi_{t+1} - \gamma_b \pi_{t-1} - \lambda m c_t) z_t] = 0 \text{ (hybrid NKPC),}$$

where the vector z_t is the set of instruments at $t-1$ and earlier.

To implement the GMM, we use the iterative GMM based on the heteroskedasticity and

⁹ Some previous studies show that simple estimation based on IVs is susceptible to weak instruments (identification) problem. For example, see Staiger and Stock (1997) and Stock et al. (2002).

autocorrelation consistent (HAC) estimator. We estimate the weighting matrix using Bartlett kernel suggested by Newey-West (1987).¹⁰ We start with the baseline set of instruments as in Gali and Gertler (1999), which consists of 6 instruments (inflation, labor share, output gap, spread between long and short interest rate, wage inflation and inflation on commodity price) with four lags. It turns out, however, that this set of instruments is rejected by the AR test, which shows the presence of weak instruments.¹¹ Therefore, we use three lags of 6 instruments instead of four lags, which pass the weak instrument test (labeled as baseline IV set 1 in Table 1). Given that a large number of instruments are more likely to yield incorrect estimates and inference in finite samples and that different choices of instruments may produce different results, we provide additional estimation results using other sets of IVs (labeled as IV sets 2 to 5 in Table 1) for robustness check.¹² These additional IV sets include inflation, labor income share and output gap as common variables and use different combinations for the rest of the variables.¹³

We apply a wide variety of model selection criteria to evaluate the empirical performance of the two hybrid NKPCs. We use two most commonly used model selection criteria for selecting competing models, AIC and BIC. We also consider RMSE, MAE, MAPE and Theil U statistics as complementary tests.¹⁴ The closer the values of RMSE, MAE and MAPE are to zero, the better the empirical performance is in terms of a model fit. For the Theil U measure, a high value implies a poor model fit. We use the Wald test for a zero restriction on the coefficient of the second lag of inflation (coefficient of the price trend) in the reduced-form (structural) generalized hybrid NKPC.

All the data are obtained from the Federal Reserve Economic Data (FRED) at the Federal Reserve Bank of St. Louis. We use the quarterly data from 1960:1 to 2007:4. The starting point of the data is 1960:1 to be comparable with Gali and Gertler (1999).¹⁵ We set the ending point of the data at 2007:4 to avoid the financial crisis period.

Inflation is defined as the percentage change of the GDP deflator (series ID: GDPDEF). We use the labor income share of nonfarm business sector (series ID: PRS85006173) as a proxy for the real marginal

¹⁰ We use the bandwidth of 10.

¹¹ The AR statistic for the generalized hybrid NKPC (hybrid NKPC) is 1.904 (1.865) with the p-value 0.006 (0.007), which imply that the null of no weak instruments is strongly rejected.

¹² The AR test results also suggest that these sets pass the weak instrument tests.

¹³ Lags of endogenous variables (inflation and labor income share) are typically used as IVs in a time-series model. For the use of output gap as an instrument, see Fuhrer and Moore (1995), Fuhrer (1997), Estrella and Fuhrer (2003), and Neiss and Nelson (2005).

¹⁴ Unlike the RMSE placing more weights on large errors due to its quadratic nature, the MAE and MAPE put equal weights on large and small errors. Since we do not include an intercept term following typical NKPC papers (e.g., Gali and Gertler 1999) and R^2 without an intercept term may mislead the interpretation of empirical results, we use the Theil U statistic in place of R^2 .

¹⁵ Earlier empirical evidence also indicates that there seems to be a structural break in inflation around 1960 (see Turnovsky 1970).

cost, constructed by two methods—log of HP-filtered and log of quadratic detrended labor share.¹⁶ Output gap is constructed by the log deviation of real GDP (series ID: GDPC1), measured by HP-filtered and quadratic detrending techniques. Unit labor cost (ULC) of nonfarm business sector (series ID: ULCNFB) is employed to obtain the wage inflation, which is defined as the percent change of the ULC. Commodity price inflation is measured by the percentage change of the producer price index of all commodities (series ID: PPIACO). We also use spread between long (series ID: INTGUSBUSM193N) and short (series ID: FEDFUNDS) interest rates.

5. Estimation Results

In this section, we present the estimation results of both reduced and structural-form generalized hybrid NKPCs to evaluate the overall performance of our model in comparison to the hybrid NKPC in Gali and Gertler (1999).

5.1. Estimation results of the reduced and structural-form equations

Table 2 reports the estimation results using the baseline instruments (IV set 1 in Table 1). The overall results from the two reduced-form specifications (generalized hybrid NKPC and hybrid NKPC) exhibit that all the estimates are highly significant. The forward-looking component in the generalized hybrid NKPC (η_f) is around 0.72 with the HP-filtered labor share (LS1) and the same coefficient in the hybrid NKPC (γ_f) is around 0.81. The backward-looking component in the generalized hybrid NKPC ($\eta_{b1} + \eta_{b2}$) is around 0.28, while the backward-looking part in the hybrid NKPC (γ_b) is around 0.19. The estimates using the quadratically detrended labor share (LS2) is similar to those with LS1 in all cases. This suggests that the forward-looking component plays a more important role than the backward-looking part in accounting for inflation dynamics, which is in line with earlier findings as in Gali and Gertler (1999), Gali et al. (2001), Sbordone (2002) and Gali et al. (2005), etc.

In the generalized hybrid NKPC, the coefficient on the second lag of inflation (η_{b2}) is positive and statistically significant around 0.11 with both LS1 and LS2.¹⁷ Therefore, the estimate of the backward-looking (forward-looking) part in the generalized hybrid NKPC is larger (smaller) than that in the hybrid NKPC with both measures of the labor share. The additional lag of inflation reduces (increases) the role

¹⁶ See Gali and Gertler (1999), Gali et al. (2001) and Sbordone (2002), etc. These studies argue that real unit labor costs are a driving force for inflation dynamics. Gali and Gertler (1999) use the percent deviation of real marginal costs from its steady state, while we use the two widely used detrending measures. For the same procedure as ours, see Mihailov et al. (2011) and Coroneo et al. (2011).

¹⁷ This result is different from Gali and Gertler (1999) who show that the coefficients on the lagged inflation terms are quite small.

of forward-looking (backward-looking) part in explaining inflation dynamics. We also perform the Wald test for a zero restriction on the coefficient of the second lag of inflation η_{b2} . The test statistics show that we can strongly reject the null of zero coefficient at 1% level, implying that the additional (second) lag of inflation is statistically meaningful and has a predictive power in explaining inflation dynamics, which is consistent with the earlier findings (e.g., Fuhrer and Moore 1995; Fuhrer 1997; Roberts 1997 and 2005). The slope coefficients on the labor share (φ and λ) are positive in both models, which is consistent with the theory, but the estimates are small and not significant.

Next, we present the estimation results of the structural models focusing on the role of the extrapolative coefficient α . With both LS1 and LS2, α is highly significant around 0.28. The Wald test statistics strongly reject the null of zero coefficient on the price trend α , implying that the data favor the generalized hybrid NKPC more than the hybrid NKPC in the statistical sense. The positive and significant α implies that the backward-looking firms consider the past trend in prices when they set their prices and the overall behavior of inflation shows a relatively stable movement (*stabilizing inflation behavior*).

The estimate for the portion of the backward-looking firms ω is highly significant in all cases. In the case of the generalized hybrid NKPC, it is around 0.48 (0.51) with LS1 (LS2), while it is around 0.22 (0.24) with LS1 (LS2) in the hybrid NKPC, which is similar to the findings in Gali and Gertler (1999). This is also associated with the findings that the backward-looking component in the reduced-form generalized hybrid NKPC (0.28) is much higher than that in the reduced-form hybrid NKPC (0.19). These results suggest that the portion of backward-looking firms is much larger in the generalized hybrid NKPC than in the hybrid NKPC. The estimate of the discount factor β is around 0.99 in all cases. This estimate is more reasonable than that in Gali and Gertler (1999) and Gali et al. (2001) where the estimated β is around 0.90 on average.

Next, we check the empirical fit of the two models by testing if the newly proposed model is preferred by the data. Table 2 shows that both AIC and BIC measures (with LS1 and LS2) from the generalized hybrid NKPC are smaller than those from the hybrid NKPC, implying that the data favor the generalized hybrid NKPC model. In addition, other criteria such as RMSE, MAE, MAPE, and Theil U from the generalized hybrid NKPC are smaller than those from the hybrid NKPC, which leads to the same conclusion. We next test the instruments exogeneity using the J test statistics. In Table 2, the J statistics indicate that we cannot reject the null hypothesis that the over-identifying assumption is satisfied. This result suggests that the instruments that we use for the baseline estimation are valid.¹⁸

¹⁸ We also test the instruments relevance using AR statistics, which are 0.813 (0.762) with the p-value 0.672 (0.739) for the generalized hybrid NKPC (hybrid NKPC). It shows that we cannot reject the null of no weak instruments,

5.2. Robustness check with different IV sets

In this section, we examine whether our baseline results are robust when different sets of IVs are used. Figure 1 displays the estimated coefficients, with the 95% confidence interval, of the reduced-form generalized hybrid NKPC with different IV sets.¹⁹ Figure 2 shows the estimated coefficients from the structural equation. All the estimates in the reduced and structural-form NKPCs are significant at 1% level, except for the estimates of the labor share.

Overall, the estimated parameter values in both reduced and structural-form equations are quite similar to those in the baseline case and the main results hold through different sets of IVs: the additional lag of inflation is statistically different from zero, implying that the second lag of inflation has a significant effect on current inflation. In the structural-form equation, the estimated coefficients on the price trend are highly significant and positive. The Wald test statistics show that the null of zero restriction on the second lag of inflation and on the coefficient of the price trend is strongly rejected. Most test statistics for model fit prefer the generalized hybrid NKPC to the hybrid NKPC. Hence, the sensitivity check suggests that our baseline results are fairly robust to different sets of instruments.

5.3. Sub-period analysis

This section presents the GMM estimation results using different sub-periods to check if the estimated coefficients are stable over different sample periods. Figures 3 and 4 display the estimation results of the reduced and structural-form generalized hybrid NKPCs, respectively.²⁰ All the results are based on benchmark IV set 1 and labor share definition 1 (LS1). We set the first sub-sample period at 1960:1~1977:4, representing the “pre-Volcker” period.²¹ The second sub-period is 1984:1~2007:4, representing the “post-Volcker” period.²² The behavior of inflation in the pre-Volcker period (until the late 1970s) is characterized by a rising pattern (*destabilizing inflation behavior*) whereas inflation in the post-Volcker period shows fairly stable movements within a certain bound (*stabilizing inflation behavior*).²³ The third sub-period is set at 1991:1~2007:4, representing the “Greenspan era” with a

implying that the choice of our set of instruments is immune to the issue of weak instruments. These results are available upon request.

¹⁹ In this section, all estimation uses the HP-filtered labor share (LS1). The results are quite similar when the quadratically detrended labor share (LS2) is used. The J and AR test statistics (which are not reported) suggest that all the instrument sets are valid, satisfying both instruments exogeneity and instruments relevance conditions.

²⁰ Most estimated coefficients are significant at 1% level except for a couple of estimates.

²¹ William Martin and Arthur Burns were in charge of the Federal Reserve during this period. The ending period is set at 1977:4 when Arthur Burns resigned from his office.

²² We set the starting period at 1984:1 following Roberts (2005). In addition, many economists argue that a new monetary regime started in 1984, which is characterized by an active monetary and passive fiscal policy (AMPF).

²³ From the econometric perspective, a clear structural break is observed between late 1970s and early 1980s, mostly due to a sudden change in monetary policy by Paul Volcker. The new regime is associated with “active or

further reduction in inflation rates, which is also characterized by the “great moderation era.” Finally, we set the fourth and fifth sub-periods at 1960:1~1997:4 and 1970:1~1998:2, respectively, following Gali and Gertler (1999) and Gali et al. (2001) for the comparison purpose.

Figure 3 displays the estimates of the reduced-form generalized hybrid NKPC with the 95% confidence interval using the data from the five sub-periods described above. Compared to the benchmark case from the whole sample period (1960:1 to 2007:4), the estimates from sub-periods do not change much except for the sub-period 1 (pre-Volcker period). In the case of sub-period 1, the coefficient on forward-looking part η_f is significantly lower around 0.4 than other sub-periods (around 0.8). The backward-looking part is around 0.6 which is significantly higher than other cases (around 0.3). This result implies that firms put more weight on the past price than the future (expected) price when they set their current price in the pre-Volcker period. The sign of the labor share is positive in all sub-samples, where the coefficient in sub-periods 1, 4 and 5 is higher than sub-periods 2 and 3. Sub-periods 1, 4 and 5 contain more pre-Volcker era, whereas the sub-periods 2 and 3 contain more post-Volcker period. Therefore, these results indicate that the Phillip curve becomes flatter over time.²⁴

Figure 4 displays the estimates of the structural generalized hybrid NKPC with the 95% confidence interval. Most coefficients do not change much over different sub-periods except for the price trend α which becomes negative around -0.7 in sub-period 1 while it stays around 0.3 in all other periods. The negative price trend in the pre-Volcker period indicates that backward-looking firms assume that the price would keep increasing when the past price shows an increasing trend, vice versa. This is due to high inflation observed in the data during the pre-Volcker period (*destabilizing inflation behavior*). On the other hand, in the post-Volcker period, the price trend is *positive*, implying that backward-looking firms assume that price would decrease when the past price shows an increasing trend. This is consistent with the observation of stable inflation during the great moderation period (*stabilizing inflation behavior*).

Another noticeable observation in Figure 4 is that the degree of price stickiness θ in the pre-Volcker period is slightly smaller than that in the post-Volcker period, which means that prices are more frequently changed in the pre-Volcker period.²⁵ In Figure 3, the pre-Volcker period (sub-period 1) also displays a higher value of labor share φ . This observation that the degree of price stickiness and labor share are negatively related is consistent with the prediction in theoretical model as shown in equation (6).

hawkish monetary policy,” contrary to the “passive or dovish monetary policy.”

²⁴ Some earlier studies document the flattening Phillips curve, in particular related to a drastic change in monetary policy since the early 1980s. For example, see Roberts (2006) and Kuttner and Robinson (2010).

²⁵ Some micro-level data show that the change in prices tends to be more frequent in high inflation period (e.g., Kashyap 1995).

6. Conclusion

In this paper, we show the validity of the extrapolative pricing behavior by empirically testing the significance of the second lag of inflation (coefficient of price trend) in the reduced-form (structural) generalized hybrid NKPC. Our model is more general and empirically better fit than the typical hybrid NKPC models that have been widely used in the literature since Gali and Gertler (1999).

While our generalized model confirms previous findings that the forward-looking behavior is more important than the backward-looking behavior for explaining inflation movements, there are some interesting new findings. First, our generalized hybrid NKPC model exhibits a much larger backward-looking component than the hybrid NKPC. Second, the estimate of the second lag of inflation (price trend) in the reduced-form (structural) equation is highly significant and has an important effect on inflation dynamics. Third, over the whole sample period, the coefficient of the price trend is positive, which implies that the backward-looking firms tend to take account of the past trend of prices when setting their prices in a stable manner (*stabilizing inflation behavior*). Fourth, unlike other sub-periods, the pre-Volker period shows that the coefficient of the price trend is negative, implying a *destabilizing inflation behavior*. Finally, all the measures of model fit indicate that the generalized hybrid NKPC model performs better than the hybrid NKPC model. Overall, the generalized hybrid NKPC with the extrapolative price-setting mechanism provides more useful insights into the nature of inflation dynamics than previous hybrid NKPC models.

References

- Anderson, T. W. and Rubin, H., 1949. Estimation of the parameters of a single equation in a complete system of stochastic equations. *Annals of Mathematical Statistics* 20(1), 46-63.
- Ball, L., 1994. Credible disinflation with staggered price-setting. *American Economic Review* 84(1), 282-289.
- Barberis, N., 2011. Psychology and the financial crisis of 2007-2008. Yale School of Management. Working Paper.
- Calvo, G. A., 1983. Staggered prices in a utility-maximizing framework. *Journal of Monetary Economics* 12(3), 383-398.
- Cavaglia, S., Verschoor, W. F. C. and Wolff, C. C. P., 1993. Further evidence on exchange rate expectations. *Journal of International Money and Finance* 12(1), 78-98.
- Chinn, M. D. and Frankel, J. A. 2000. Survey data on exchange rate expectations: more currencies, more horizons, more tests. Working Paper.
- Christiano, L., Eichenbaum, M., and Evans, C., 2005. Nominal rigidities and the dynamic effects of a shock to monetary policy. *Journal of Political Economy* 113(1), 1-45.
- Coroneo, L., Corradi, V. and Monteiro, P. S., 2011. Testing for the degree of commitment via set-identification. Working Paper.
- De Bondt, W. P. M., 1993. Betting on trends: intuitive forecasts of financial risk and return. *International Journal of Forecasting* 9(3), 355-371.
- Estrella, A. and Fuhrer, J. C., 2003. Monetary policy shifts and the stability of monetary policy models. *Review of Economics and Statistics* 85(1), 94-104.
- Frankel, J. A. and Froot, K. A., 1987a. Using survey data to test standard propositions regarding exchange rate expectations. *American Economic Review* 77(1), 133-153.
- Frankel, J. A. and Froot, K. A., 1987b. Short-term and long-term expectations of the yen/dollar exchange rate: evidence from survey data, *Journal of the Japanese and International Economies* 1(3), 249-274.
- Fuhrer, J. C., 1997. The (un)importance of forward-looking behavior in price specifications. *Journal of Money, Credit, and Banking* 29(3), 338-350.
- Fuhrer, J. C. and Moore, G. R., 1995. Inflation persistence. *Quarterly Journal of Economics* 110(1), 127-159.
- Gali, J. and Gertler, M., 1999. Inflation dynamics: a structural econometric analysis. *Journal of Monetary Economics* 44(2), 195-222.
- Gali, J., Gertler, M. and Lopez-Salido, J. D., 2001. European inflation dynamics. *European Economics Review* 45(7), 1237-1270.

- Gali, J., Gertler, M. and Lopez-Salido, J. D., 2005. Robustness of the estimates of the hybrid New Keynesian Phillips curve. *Journal of Monetary Economics* 52(6), 1107-1118.
- Gerardi, K. S., Lehnert, A., Sherlund, S. M. and Willen, P. S., 2008. Making sense of the subprime crisis. *Brookings Papers on Economic Activity*, 69-145.
- Goodwin, R. M., 1947. Dynamical coupling with especial reference to markets having production lags. *Econometrica* 15(3), 181-204.
- Johnson, M. D. and Plott C. R., 1989. The effect of two trading institutions on price expectations and the stability of supply-response lag markets. *Journal of Economic Psychology* 10(2), 189-216.
- Kashyap, A. K., 1995. Sticky prices: new evidence from retail catalogs. *Quarterly Journal of Economics* 110(1), 245-274.
- Kozicki, S. and Tinsley, P. A., 2002. Alternative sources of the lag dynamics of inflation. FRB Kansas City Research Working Paper No. 02-12.
- Kuttner, K. and Robinson, T., 2010. Understanding the flattening Phillips curve. *North American Journal of Economics and Finance* 21(2), 110-125.
- Metzler, L. A., 1941. The nature and stability of inventory cycles. *Review of Economics and Statistics* 23(3), 113-129.
- Mihailov, A., Rumler F. and Scharler J., 2011. The small open-economy new Keynesian Phillips curve: empirical evidence and implied inflation dynamics. *Open Economies Review* 22(2), 317-337.
- Muth, J. F., 1961. Rational expectations and the theory of price movements 29(3), 315-335.
- Neiss, K. S. and Nelson, E., 2005. Inflation dynamics, marginal cost, and the output gap: evidence from three countries. *Journal of Money, Credit, and Banking* 37(6), 1019-1045.
- Newey, W. K. and West, K. D., 1987. A simple, positive-definite, heteroskedasticity and autocorrelation consistent covariance matrix. *Econometrica* 55(3), 703-708.
- Pfajfar, D. and Zakelj, B., 2013. Inflation expectations and monetary policy design: evidence from the laboratory. Working Paper.
- Reckwerth, J., 1997. Inflation and output in Germany: the role of inflation expectations. Economic Research Group of the Deutsche Bundesbank Discussion Paper 5/97.
- Roberts, J. M., 1997. Is inflation sticky? *Journal of Monetary Economics* 39(2), 173-196.
- Roberts, J. M., 2005. How well does the New Keynesian sticky-price model fit the data? *B.E. Journal of Macroeconomics* 5(1).
- Roberts, J. M., 2006. Monetary policy and inflation dynamics. *International Journal of Central Banking* 2(3), 193-230.
- Sbordone, A. M., 2002. Prices and unit labor cost: a new test of price stickiness. *Journal of Monetary*

Economics 49(2), 265-292.

Sbordone, A. M., 2006. U.S. wage and price dynamics: A limited information approach. *International Journal of Central Banking* 2(3), 155-191.

Sirri, E. R. and Tufano P., 1998. Costly search and mutual fund flows. *Journal of Finance* 53(5), 1589-1622.

Smets, F. and Wouters, R., 2003. An estimated dynamic stochastic general equilibrium model of the Euro area. *Journal of the European Economic Association* 1(5), 1123-1175.

Staiger, D. and Stock J. H., 1997. Instrumental variables regression with weak instruments. *Econometrica* 65(3), 557-586.

Stock, J. H., Wright, J. H. and Yogo, M., 2002. A survey of weak instruments and weak identification in generalized method of moments. *Journal of Business and Economic Statistics* 20(4), 518-529.

Svendsen, I., 1994. Do Norwegian firms form extrapolative expectations? Research Department of Statistics Norway, Discussion Papers 126.

Turnovsky, S. J., 1970. Empirical evidence on the formation of price expectations. *Journal of the American Statistical Association* 65(332), 1441-1454.

Vissing-Jørgensen, A., 2003. Perspectives on behavioral finance: does 'irrationality' disappear with wealth? evidence from expectations and actions. *NBER Macroeconomics Annual* 18, 139-194.

Table 1. Sets of instrumental variables (IVs)

<i>IV set</i>	<i>List of Instrumental Variables (IVs)</i>
<i>IV set 1</i>	inflation, labor share, output gap, long-short spread of interest rates, wage inflation, inflation on commodity price
<i>IV set 2</i>	inflation, labor share, output gap, long-short spread of interest rates, wage inflation
<i>IV set 3</i>	inflation, labor share, output gap, wage inflation, inflation on commodity price
<i>IV set 4</i>	inflation, labor share, output gap, long-short spread of interest rates
<i>IV set 5</i>	inflation, labor share, output gap, wage inflation

Note: 1. All the instruments have three lags.

2. IV set 1 is used for the baseline case.

3. For IV set 5, we use the same variables as in Gali et al. (2001) except for the number of lags.

Table 2. Baseline estimation results using IV set 1

<i>Reduced-form Equations</i>										
<i>Reduced-form Generalized Hybrid NKPC</i>							<i>Reduced-form Hybrid NKPC</i>			
<i>LIS</i>	η_f	η_{b1}	η_{b2}	φ	<i>J-Stat</i>	<i>W-Stat</i>	γ_f	γ_b	λ	<i>J-Stat</i>
<i>LS1</i>	0.718*** (0.042)	0.168*** (0.047)	0.109*** (0.035)	0.001 (0.006)	7.656 (0.907)	9.653 (0.001)	0.807*** (0.046)	0.188*** (0.046)	0.003 (0.006)	8.759 (0.890)
<i>LS2</i>	0.710*** (0.041)	0.173*** (0.046)	0.113*** (0.036)	0.003 (0.004)	7.826 (0.898)	10.225 (0.001)	0.797*** (0.045)	0.199*** (0.045)	0.001 (0.005)	9.095 (0.873)
<i>Structural Equations</i>										
<i>Structural Generalized Hybrid NKPC</i>							<i>Structural Hybrid NKPC</i>			
<i>LIS</i>	β	θ	ω	α	<i>J-Stat</i>	<i>W-Stat</i>	β	θ	ω	<i>J-Stat</i>
<i>LS1</i>	0.992*** (0.016)	0.895*** (0.063)	0.478*** (0.092)	0.284*** (0.064)	7.654 (0.907)	19.414 (0.000)	0.992*** (0.011)	0.936*** (0.069)	0.215*** (0.060)	8.756 (0.890)
<i>LS2</i>	0.992*** (0.018)	0.923*** (0.068)	0.514*** (0.099)	0.285*** (0.063)	7.826 (0.898)	20.495 (0.000)	0.993*** (0.011)	0.969*** (0.111)	0.240*** (0.064)	9.095 (0.873)
<i>Measures for Model Performance</i>										
	<i>AIC</i>	<i>BIC</i>	<i>RMSE</i>	<i>MAE</i>	<i>MAPE</i>	<i>TheilU</i>				
<i>GH (LS1)</i>	472.575	485.500	0.256	0.196	25.707	0.227				
<i>H (LS1)</i>	484.142	493.835	0.265	0.200	25.981	0.236				
<i>GH (LS2)</i>	471.471	484.395	0.255	0.196	25.705	0.227				
<i>H (LS2)</i>	482.119	491.813	0.263	0.198	25.896	0.235				

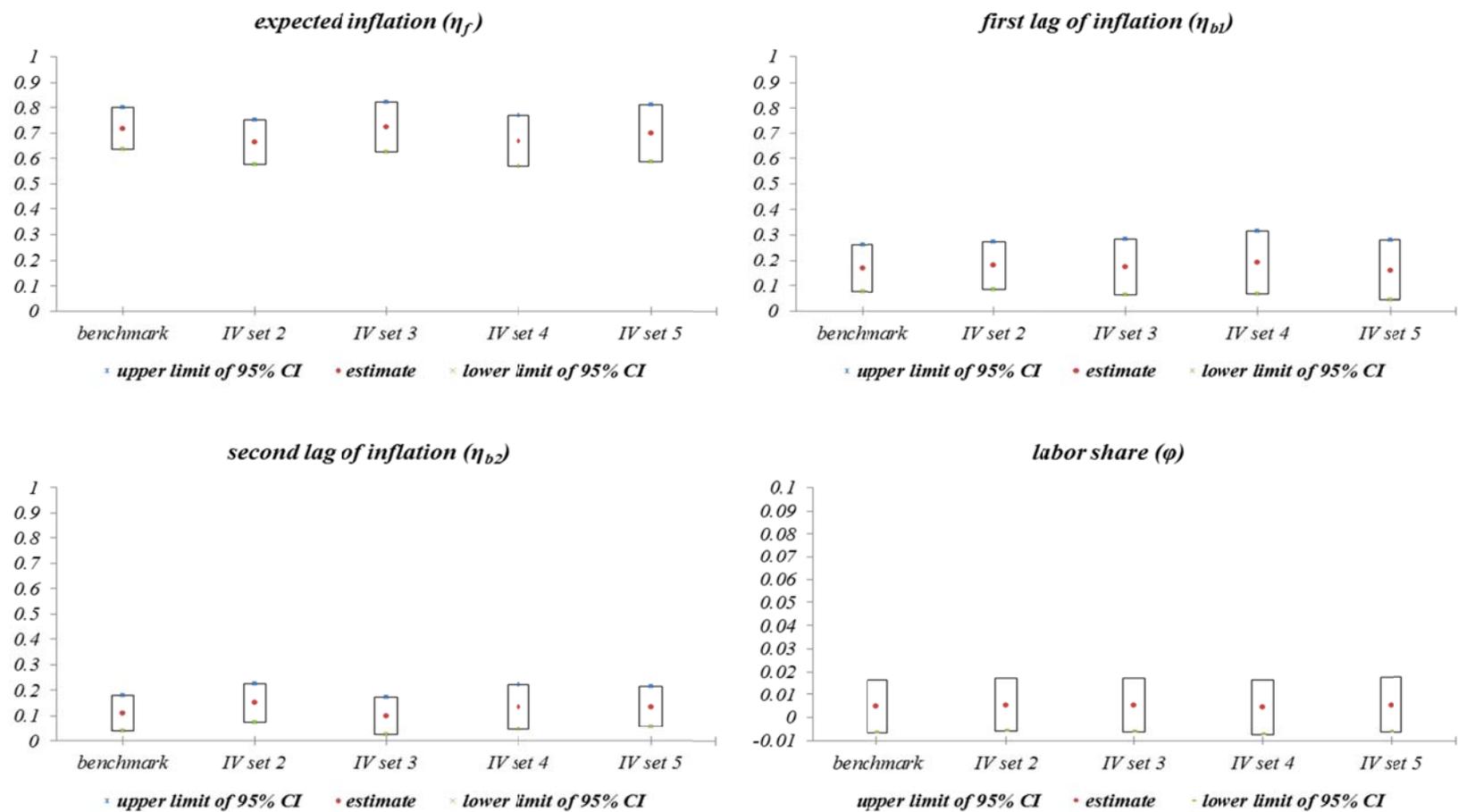
Note: 1. ***, ** and * denote the significance levels at 1%, 5% and 10%, respectively.

2. LIS denotes for labor income share. LS1 and LS2 are the HP-filtered labor share and the quadratically-detrended labor share respectively. GH denotes for the generalized hybrid NKPC and H denotes for the hybrid NKPC.

3. J-Stat denotes for J Statistics and W-Stat denotes for Wald statistics.

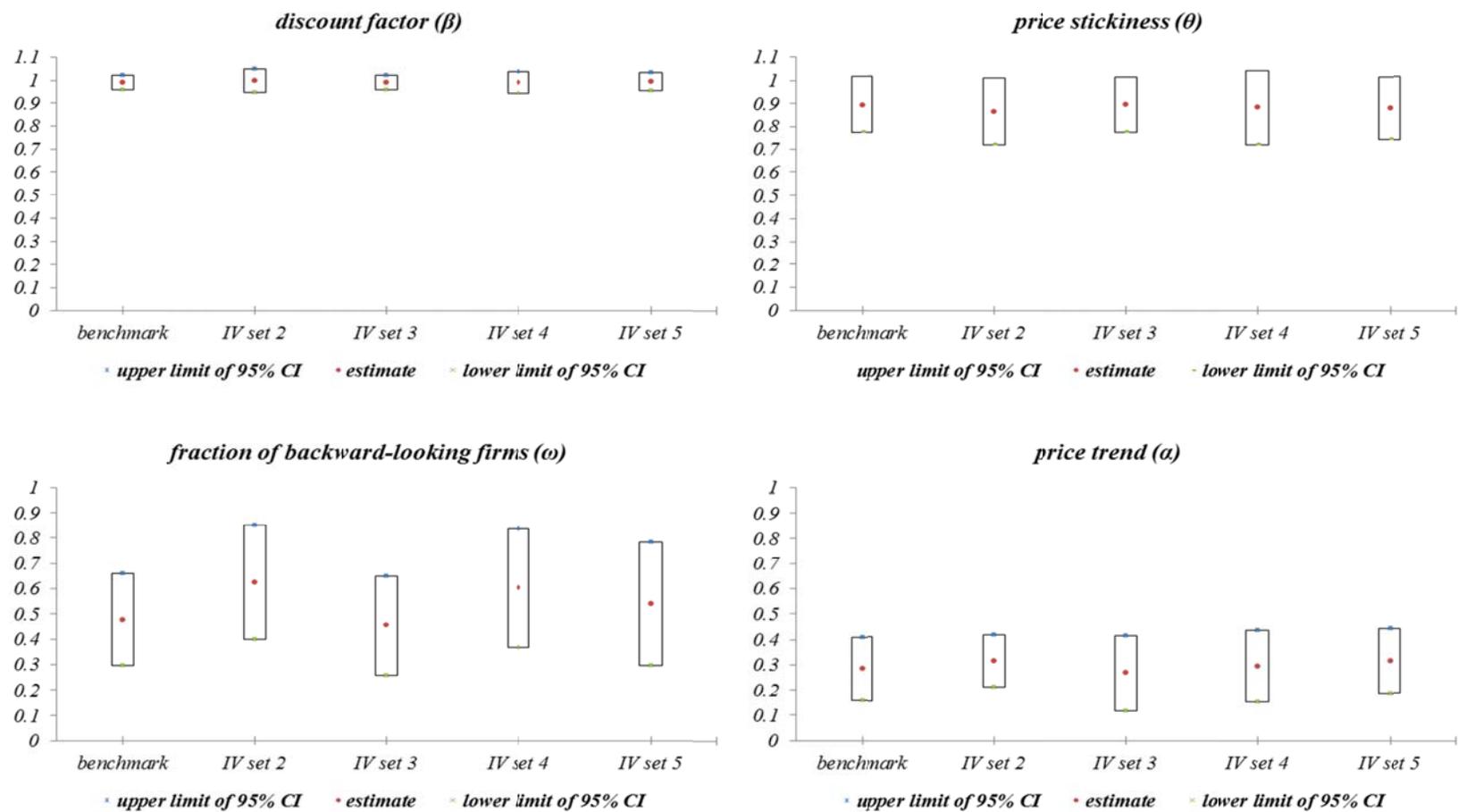
4. Parentheses below the estimated coefficients indicate the standard errors, whereas parentheses below statistics indicate p-values.

Figure 1. Robustness check using various IV sets: *Reduced-form generalized hybrid NKPC*



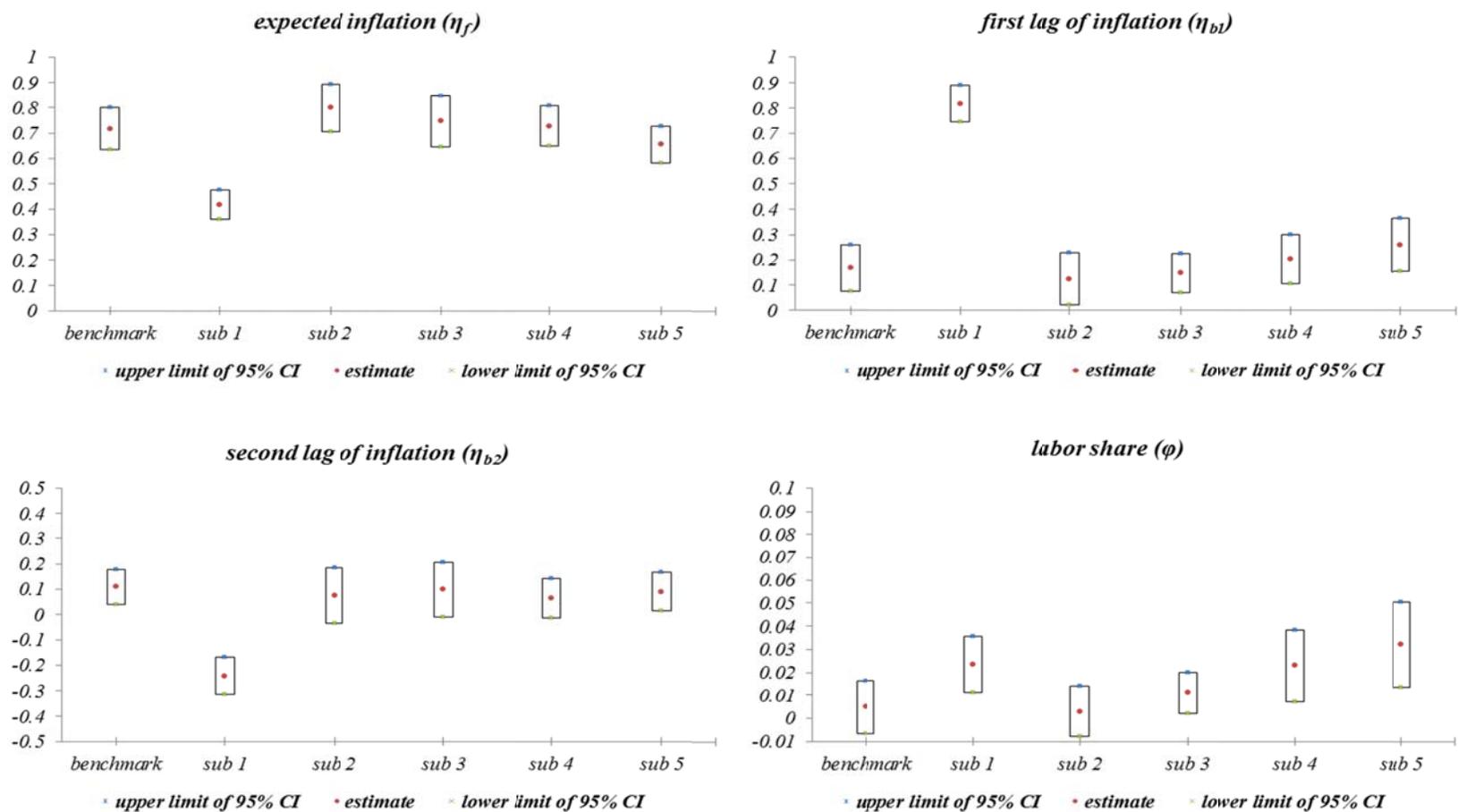
Note: Instruments for each IV set are described in Table 1.

Figure 2. Robustness check using various IV sets: *Structural generalized hybrid NKPC*



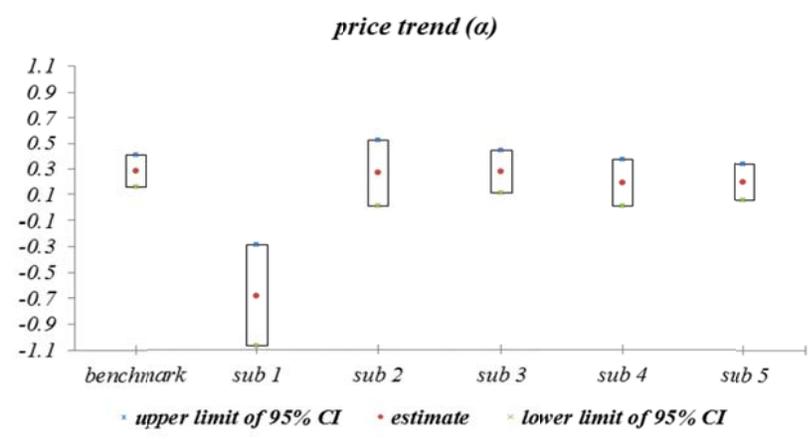
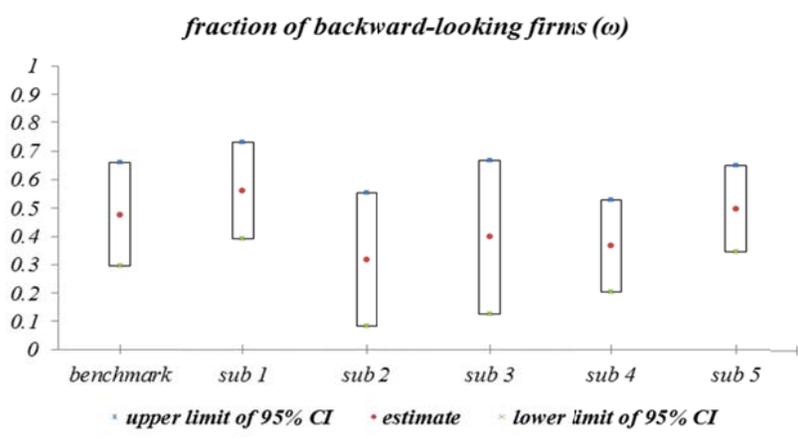
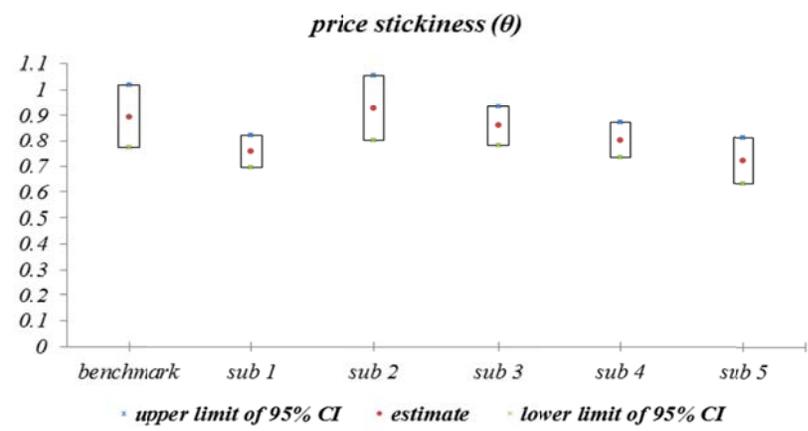
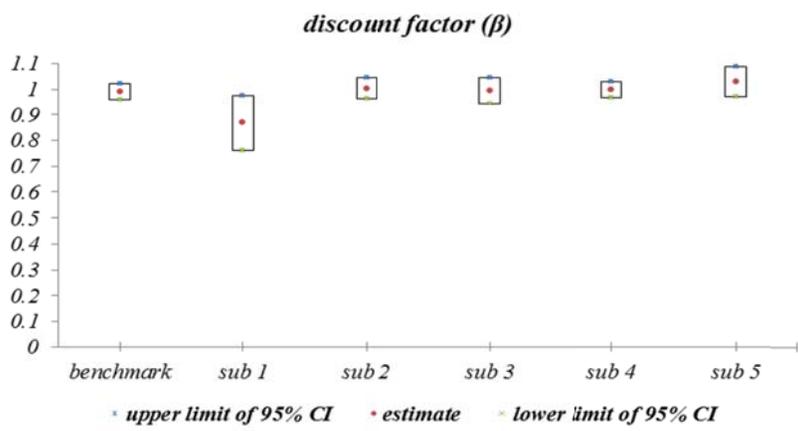
Note: Instruments for each IV set are described in Table 1.

Figure 3. Sub-period analysis: *Reduced-form generalized hybrid NKPC*



Note: Sub 1, 2, 3, 4 and 5 indicate 1960:1 ~ 1977:4, 1984:1 ~ 2007:4, 1991:1 ~ 2007:4, 1960:1 ~ 1997:4 (Gali and Gertler, 1999), 1970:1 ~ 1998:2 (Gali et al., 2001), respectively.

Figure 4. Sub-period analysis: *Structural generalized hybrid NKPC*



Note: Sub 1, 2, 3, 4 and 5 indicate 1960:1 ~ 1977:4, 1984:1 ~ 2007:4, 1991:1 ~ 2007:4, 1960:1 ~ 1997:4 (Gali and Gertler, 1999), 1970:1 ~ 1998:2 (Gali et al., 2001), respectively.